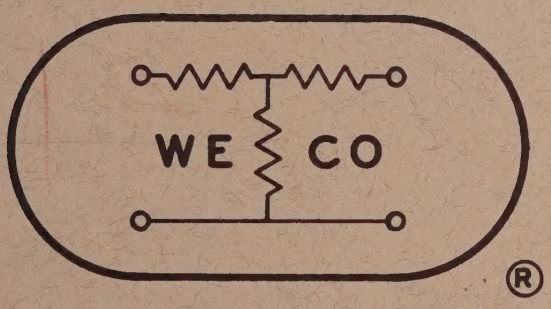
INSTRUCTION MANUAL
Model BA-5
ATTENUATION CALIBRATOR



Weinschel Engineering
Kensington, Maryland

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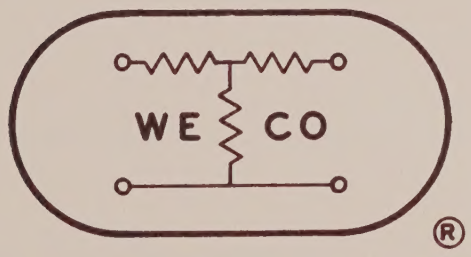

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IM #2 - 1960

Revised July, 1960

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SECTION 1

GENERAL INTRODUCTION

1.1 Scope of Manual.

This manual covers the description, theory of operation, operating procedure, and maintenance instructions for the Model BA-5 Attenuation Calibrator.

1.2 Purpose of Equipment.

This equipment is intended to be used for the accurate measurement of r.f. power ratios when used with a square law detector and certain other equipment to be described later.

Power ratio measurements are required in many applications. Some typical examples are: determination of antenna patterns, insertion loss, amplifier gain and standing wave ratio. These applications will be treated in more detail in subsequent sections of this manual.

1.3 Specifications.

1.3.1 Attenuation Range: Continuous over a range of 52 db at r.f. when using a square law detector corresponding to a 104 db range at the audio frequency used.

1.3.2 Attenuator Accuracy: Better than 0.02 db at r.f. for r.f. power ratios up to 30 db for any combination. Resolution capability is .002 db. Accuracy of a measurement is dependent on several other factors. See Sections 2 and 3.

1.3.3 Frequency: Audio - 1000±3 cycles per second. R.F. - any for which bolometers, bolometer mounts and other required accessories are available. See Sections 2 and 3.

1.3.4 Bandwidth: Less than 35 cycles per second between 3 db points.

1.3.5 Input Impedance: Approximately 2000 ohms. Intended for use with bolometers having a d.c. resistance between 50 and 200 ohms.

1.3.6 Voltage Gain: Between input and output connectors approximately 5×10^6 max. adjustable over a range of 80 db. At full gain and the attenuator at zero, approximately a 0.3 microvolt signal will produce full scale deflection on the output meter.

1.3.7 Maximum Output Voltage: 1.5 volts, r.m.s to external indicator.

1.3.8 Equivalent Noise: Less than 30 millimicrovolts r.m.s. referred to the input when connected to a shielded 200 ohm wirewound resistor.

1.3.9 Bolometer Bias Current: Adjustable from 3-9 ma. d.c. from a constant current supply. The bolometer can be connected or disconnected and the power switched on and off without damage to the bolometer.

1.3.10 Output Impedance: Approx. 250 ohms. Load impedance for minimum distortion should be greater than 10,000 ohms.

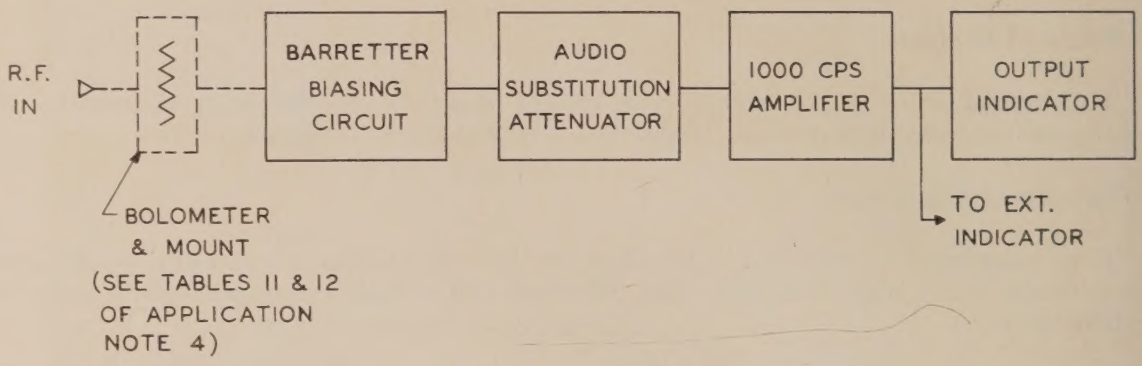

R.F. IN
BARRETTER BIASING CIRCUIT
AUDIO SUBSTITUTION ATTENUATOR
1000 CPS AMPLIFIER
OUTPUT INDICATOR
TO EXT. INDICATOR
BOLOMETER & MOUNT (SEE TABLES II & 12 OF APPLICATION NOTE 4)

Figure 1. Block Diagram - BA-5

1.3.11 Controls: "Attenuation" - Four (4) lever switches - 10 db each; one eleven (11) position switch covering 0 to 10 db in 1 db steps; one twelve (12) position switch covering 0 to 1 db in one step and 1.0 to 2.0 db in 0.1 db steps; and a continuous control covering minus .01 to plus .11 db.

"Gain" - A coarse control with 7 steps of approximately 10 db (A.F.) each and a fine control with a continuous range of approximately 10 db (A.F.).

"Meter Time Constant" - A two position switch with "short" and "long" positions.

"Bolometer Current Adjust" - Screwdriver adjustment available from front panel.

"Power, On-Off" - Toggle switch with red pilot light indicator.

1.3.12 Connectors: "Input" - BNC female, front panel mounted.
"Output" - BNC female, front panel mounted.
"Power" - Standard 115 volt, 2 wire recessed male cap on rear of chassis.

1.3.13 Fuse: 3 Amp. Bussman AGC, mounted on rear of chasis.

1.3.14 Primary Power: 105-125 volts, 60 cps, 190 VA.

1.3.15 Ambient Temperature: 15^{o}C to 35^{o}C.

1.3.16 Dimensions: Standard relay rack mounting. Panel - 10-1/2 in. x 19 in. Maximum depth behind panel - 13-1/2 in.

1.3.17 Weight: 35 pounds.

Figure 2. Front Panel View - BA-5

1.4 Description.

The Model BA-5 Attenuation Calibrator consists of a precision audio attenuator, a low noise amplifier selective to 1000 cps and an indicator provided with VSWR and DB scales. A cathode follower output allows the use of an external meter or recorder. This output is also used when the instrument is used in the dual channel test set (see Section 3.2). A block diagram is shown in figure 1 and photographs of the equipment are shown in figures 2, 3 and 4.

In use, audio attenuation is substituted for r.f. attenuation to maintain the output constant. It is designed for use with a square law detector which means that the voltage input to the BA-5 is proportional to the power input to the bolometer. Therefore, a given change in r.f. level at the bolometer input (measured in decibels) results in twice this change (again measured in decibels) in the audio level. The substituted audio attenuation is, therefore, twice the r.f. attenuation. The audio attenuator on the BA-5 is calibrated in equivalent r.f. decibels when using a square law detector and this factor of two need not be considered unless the attenuator is used to measure attenuation at 1000 cps when the audio attenuation will be twice the indicated attenuation.

The audio attenuator impedance is 2000 ohms which produces negligible loading of the 200 ohm bolometer.

The BA-5 contains a constant current bolometer bias supply and is also provided with a meter indicating bolometer current. Bolometer current is continuously adjustable over a range of from 3 to 9 ma. It can also be turned off completely by rotating the control to its extreme CCW position. This is necessary if a crystal is used in place of a bolometer.

The audio attenuator is followed by a low noise, linear amplifier sharply selective to 1000 cps. By placing the amplifier after the attenuator, the amplifier operates at a constant level during any one measurement and small non-linearities in the amplifier response do not affect the accuracy of the measurement. The amplifier input circuit is carefully laid out and shielded to keep the noise pickup to a minimum. The amplifier may be operated within reasonable distance of a.c. power supplies and other 60 cycle equipment without excessive hum pickup.

The amplifier is followed by an indicator and cathode follower which provides an output for an external indicator or recorder.

The indicator is provided with a "short" and "long" time constant to allow accurate measurements to be made at levels such that the noise present would normally cause appreciable meter fluctuation. By using the "long" time constant under these conditions, the meter reading is averaged with very little resulting error.

The meter is provided with both VSWR and DB scales so that the equipment can also be used for VSWR measurements in the usual manner.

1.5 Unpacking and Preparation for Use.

The BA-5 is shipped in a double carton with three (3) inches of packing material between the inner and outer cases. Normal care should be exercised in removing the instrument and packing material from the case. There should be no loose items with the exception of the line cord and the Instruction Manual. Tubes are shipped in place.

After unpacking the instrument, examine it for mechanical damage. If any damage is found, notify the shipping company immediately.

Remove the bottom cover of the chassis and examine the leads connecting the two floating chassis to insure that no lead has been broken in transit. Check ground connections. Erratic grounds can produce severe oscillation conditions which render the instrument useless. Remove the jumper across the meter terminals and the blocks from the floating chassis.

Check the condition of the 3 amp Bussman AGC fuse. Be sure that all tubes are firmly seated.

Turn the bolometer bias control to its maximum counter-clockwise position.

The other equipment required will depend on the purpose for which the instrument is to be used. (See Section 3). Although the instrument is thoroughly shielded, endeavor to keep it away from high intensity r.f. fields. Be sure that the line voltage is within the operating limits. If necessary, use an a.c. voltage regulator to provide the proper a.c. line voltage at all times or accuracy of instrument may be impaired.

1.6 Preliminary Precautions.

Keep the coaxial input cable from the bolometer to the input of the BA-5 as short as conveniently possible. Under no circumstances, allow it to exceed three feet in length. Do not permit any coaxial cable to pass through a strong magnetic field at the modulating frequency since the cable shielding is ineffective against low frequency magnetic disturbances. Do not place the BA-5 too close to or in the same metal rack

as the audio modulator for the r.f. source. Avoid ground loops when connecting shielded cables. If a stabilized voltage regulator is used, it is wise to keep it as far away as conveniently possible from the test set-up.

After the above precautions have been observed, set the "coarse" and "fine" gain controls to their maximum counter-clockwise position. Plug in the line cord and switch on the power. Allow the equipment to warm up for five minutes. Connect the bolometer cable to "Input" and set the bolometer current with a screwdriver through the hole in the front panel marked "Adjust" until the bolometer current meter indicates the correct operating current for the bolometer used.

The instrument is now ready for use.

SECTION 2

THEORY OF OPERATION

2.1 General.

The use of an audio substitution method of measurement of r.f. insertion loss is described in "Technique of Microwave Measurements" by C. G. Montgomery (Vol. 11 of the M.I.T. Rad. Lab. Series) pp. 806-808 and 838-841.

This method is based on the assumption that the application of a modulated r.f. signal to a biased bolometer results in a resistance variation in the bolometer that is proportional to the r.f. power applied. If this resistance variation is used to develop the input voltage to an amplifier or voltmeter, it is possible to measure power ratios at the bolometer input by measuring voltage ratios at the bolometer output. This measurement can be accomplished over a limited range by using a well-calibrated voltmeter and remembering that an N db change in audio level corresponds to an N/2 db change in the r.f. level.

A preferable method is to use an accurate audio attenuator in a substitution arrangement in which case the indicator is used only as an index to allow the operator to maintain the audio level constant as r.f. attenuation is inserted. The Model BA-5 has been designed to do this job with good accuracy and requires a minimum amount of operator skill. There are two recommended set-ups in which it can be used. They are described in Section 3, Operating Procedures.

2.2 Barretter.

A barretter is used with this equipment since its thermal time constant is short enough so that the resistance variations follow the 1000 cycle modulation on the input r.f. signal and thereby produce a reasonable output voltage. The barretter also follows a square law quite closely over an appreciable power range. The departure from square law and means of correcting for it are discussed in paragraph 3.3.2.

In operation, the barretter is biased with a fixed current. When r.f. power is applied, the barretter resistance varies in accordance with this power. If a constant current bias supply is used, the voltage across the barretter varies according to the r.f. power dissipated in the barretter and if the r.f. input signal is square wave modulated at an audio rate, the audio voltage developed across the barretter is proportional to the r.f. power dissipated.

The BA-5 contains a well filtered, constant current barretter bias supply and a front panel meter so that the current can be continuously monitored. A screwdriver control, available from the front panel, allows adjustment of the bias current to the proper value for the barretter being used.

The barretter bias circuit used in the BA-5 has the added advantage that it allows the operator to connect and disconnect the barretter at will without danger of burning it out due to transient current surges.

2.3 The BA-5 Attenuation Calibrator.

A block diagram of the BA-5 is shown in figure 1 and photographs in figures 2, 3 and 4. Figure 6 shows a schematic circuit diagram.

From figure 1, it can be seen that the BA-5 consists of four principal parts: the barretter biasing circuit, the audio substitution attenuator, the 1000 cps amplifier and the output indicator. The operation of each part is discussed below.

2.3.1 The Barretter Biasing Circuit: The importance of this circuit can be appreciated from paragraph 2.2 above. Any noise on the barretter bias current appears at the amplifier and limits the smallest signal that can be detected. Reference to the schematic, figure 5, will show the care that has been taken to filter the biasing current and to prevent damage to the barretter due to current surges that might otherwise occur during connection and disconnection of the barretter.

2.3.2 The Audio Substitution Attenuator: This consists of a series of switch selected, resistive "T" pads with a characteristic impedance of 2000 ohms. The attenuation can be varied in steps of 10 db, 1.0 db and 0.1 db. In addition, there is a continuous vernier that covers a range of slightly over 0.1 db for fine adjustments.

The relatively high attenuator impedance (2000 ohms) loads the barretter by a negligible amount since it is biased to approximately 200 ohms.

As explained in paragraph 2.1, the substituted audio attenuation in decibels is twice the r.f. attenuation being measured. To allow the measurements to be made with a minimum of computation, the audio substitution attenuator is calibrated directly in r.f. db.

2.3.3 The 1000 CPS Amplifier: The amplifier consists of vacuum tubes V-5, V-6, V-7, V-8, V-9 and V-10, as shown in figure 6. The audio attenuator is terminated by the primary of the input transformer T-4 and the resistors R-13 and P-5. These are factory adjusted to provide the proper terminating resistance for the attenuator. The secondary of the transformer drives the grid of V-5. The input transformer T-4 is a special transformer provided with a very effective magnetic shield to keep the noise pickup at an acceptable low level.

The amplifier proper consists of two feedback amplifiers in cascade. The first employs a twin "T" feedback circuit tuned to 1000 cycles. At frequencies far from 1000 cycles, a large amount of negative feedback is applied to the grid of V-5, while at 1000 cycles, the feedback voltage is greatly reduced. The gain therefore at 1000

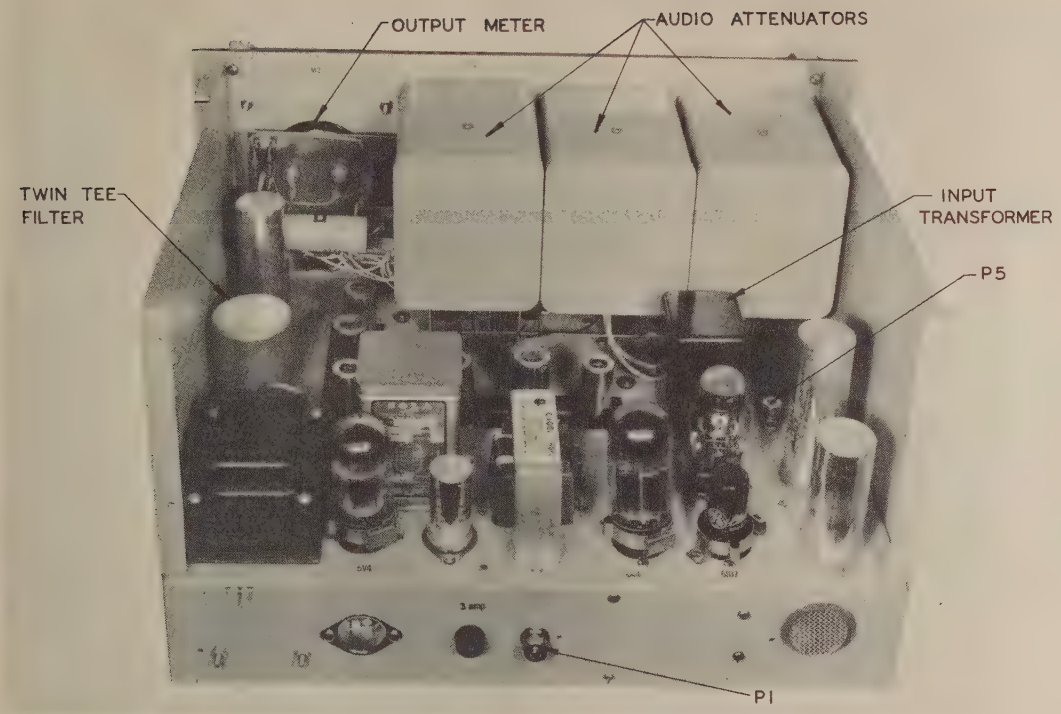


Figure 3. Back Panel View - BA-5

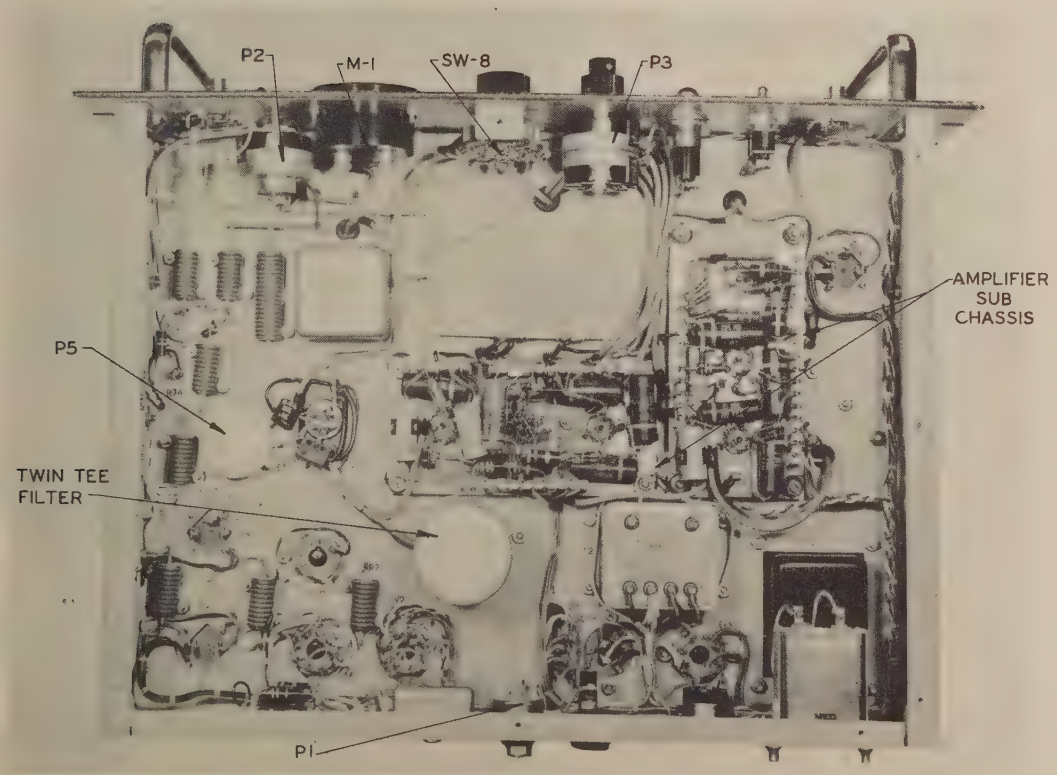


Figure 4. Under Chassis View - BA-5

cycles is high and a resonant effect is noted. Medium and fine gain controls are located between the two halves of V-6. A coarse gain control is located between V-6 and V-7 and consists of a tapped voltage divider. Each step on the switch corresponds to a gain change of approximately 10 db. A feedback circuit similar to the one previously described is placed around V-9 and V-8. As indicated in the specifications paragraph 1.3.4, the over-all bandwidth is less than 35 cycles.

The substitution attenuator control providing the .01 db resolution is actually a precision potentiometer used as a gain control and located between the two halves of V-9.

A dual triode V-10 serves the functions of driving the output indicator and providing an output to drive an external indicator.

2.3.4 The Indicator: The germanium diodes, CR-2 and CR-3, rectify the output of one-half of V-10 to provide drive for the output indicator. The output meter is provided with a mirror scale, to allow accurate resetting of the indicator, and with a decibel scale and VSWR scale. The decibel scale makes it convenient to estimate small changes in attenuation and it should be borne in mind that the attenuation is in terms of r.f. loss, not audio. See Sections 1.4 and 2.1. The VSWR scale is also calibrated for use with a square law detector.

C-27 and C-28 provide for long and short indicator time constants respectively. The short time constant should be used except where it is required to make measurements employing low levels, such that the circuit noise causes an excessive fluctuation on the output indicator. Under these circumstances, the long time constant can be used to allow accurate determination of the indicator reading.

SECTION 3

OPERATING PROCEDURE

3.1 A Single Channel Set-Up.

The Model BA-5 can be used in the set-up as shown in figure 5 to measure insertion loss up to 30 db at any frequency where the proper accessories are available. The range of 30 db is limited by the linear range of the barretters used and the internal noise of the BA-5. The accuracy with which measurements can be made using this set-up is limited by the amplitude stability of the r.f. source and the resolution with which the output indicator can be returned to a given reading.

A 100% square wave modulated r.f. source with a power output of at least 20 milliwatts is employed as a power source. At least a 20 db, and preferably a 30 db, pad is used following the source to prevent any reaction on the source by insertion of the unit under test.

It is usually required that the insertion loss of a unit be measured between points having impedances equal to the characteristic impedance of the unit under test. If, therefore, the pad following the r.f. source does not have a low VSWR looking back toward the generator, a matching device, such as a double stub tuner, should be used following it. A slotted line and VSWR indicator is shown ahead of the unit under test, since it is usually required that a VSWR measurement be made at the same time as an

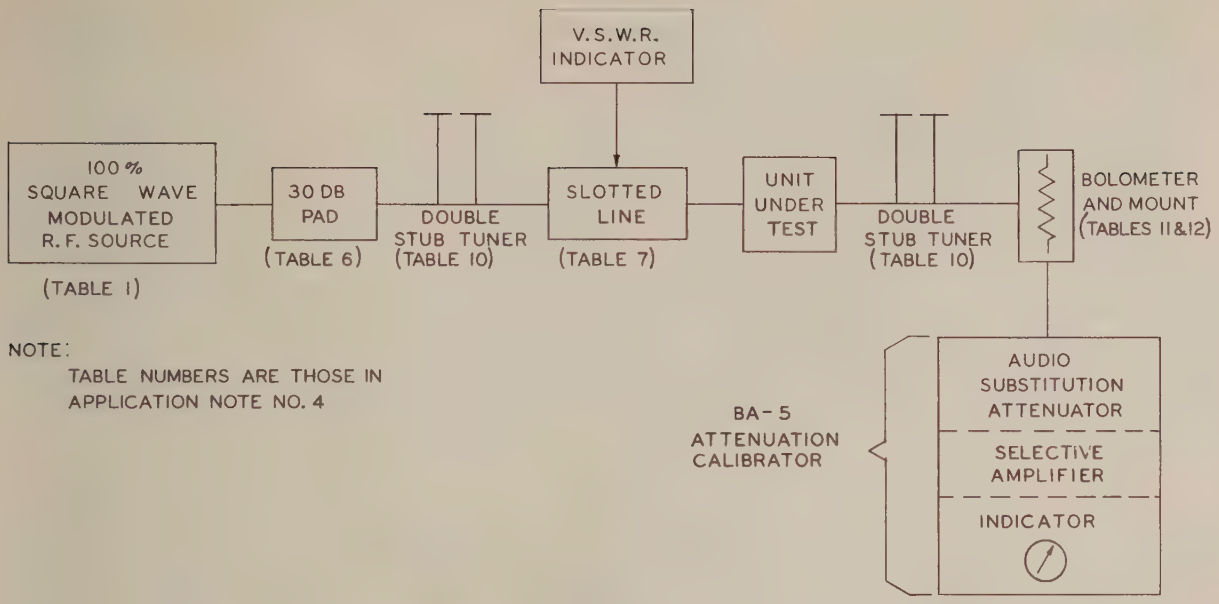


Figure 5. Single Channel Block Diagram

insertion loss measurement. The r.f. signal is demodulated by means of a bolometer and the resulting 1000 cycle signal fed to the BA-5. The VSWR looking into the bolometer mount should be low if an accurate measurement is to be made. This can be done by use of a broad band bolometer mount or by use of a matching device such as a double stub tuner ahead of the mount.

In making this set-up, and assuming the use of a Polytechnic Research and Development Model 610-A barretter, the maximum power applied to the barretter should not exceed 200 microwatts. This will provide an audio voltage of approximately 2 millivolts at the input to the BA-5. A convenient means of checking this is to set the gain controls on the BA-5 at their minimum (counter-clockwise) position and all audio attenuators set to zero. The r.f. power is then adjusted to give a reading on the BA-5 output indicator of approximately full-scale. For this adjustment, the unit under test should, of course, be out of the set-up.

To make a measurement, the audio substitution attenuator is set at a setting several db greater than the expected attenuation to be measured. The BA-5 gain is then adjusted to produce a convenient reading on the output indicator of approximately full scale. It is advisable to make this reading correspond to one of the fine divisions on the meter scale since it is easier to accurately reset the meter under these conditions. The unit under test is then inserted as shown in figure 5 and audio attenuation is removed until the original meter reading is obtained. The difference between the two settings of the audio attenuator is then equal to the attenuation of the unit under test.

For the maximum accuracy to be obtained from the above procedure, it is necessary that the proper accessories be used. In the following paragraphs, some of the requirements of these accessories are set forth. There are several tables of recommended accessories shown in Application Note No. 4 which is included as a part of this Manual.

3.1.1 The RF Source: It is necessary that the r.f. source be 100% square wave modulated at 1000 cycles. The stability of the modulation frequency is important since a fairly narrow band amplifier is used in the BA-5. Weinschel Engineering makes sources covering the frequency range from 50 to 11,000 megacycles with built-in square wave modulators having the required stability. In addition, a Model MO-1A modulator is available for use with generators that do not have provision for internal square wave modulation at 1000 cycles. The r.f. source should be capable of delivering at least 20 milliwatts into a 50 ohm load. This allows 20 db of padding to be used following the generator. If additional power is available, additional padding can be used but, in no case, should less than 20 db be used. The generator should also possess a high degree of amplitude stability since any variation in the output during a measurement will result in an error. The generators manufactured by Weinschel Engineering are provided with a means of amplitude stabilization. A directional coupler is used to sample the incident power in the output line and this is fed back through the oscillator power supply to hold the output at a fixed level.

The frequency stability of most sources is quite sufficient. However, a very great frequency shift cannot be tolerated if broad band components are not used in the set-up. For instance, if a double stub tuner is used to provide the proper input impedance to a bolometer mount, this impedance can be very greatly dependent on frequency and a small frequency variation in the generator output can cause an appreciable error.

For a list of the recommended sources, see Table 1, Application Note No. 4.

3.1.2 Bolometer and Bolometer Mount: As explained earlier, it is necessary that the bolometer used be provided with the proper biasing current. This biasing current should be determined for the particular bolometer being used and care should be taken to adjust it properly. A bolometer requiring a bias current of 4.5 milliamperes may burn out if as much as 4 milliwatts of r.f. power is added, while the ones employing a bias current of 8.75 milliamperes may burn out if 16 milliwatts of r.f. power is added. Tables 11 and 12, Application Note No. 4, list the recommended barretters and mounts for use with this set-up.

3.2 A Dual Channel Set-Up.

In 3.1 above, a single channel set-up employing the Model BA-5 is described. To increase the accuracy, particularly when measuring low insertion loss, a dual channel set-up is advisable. Such a set-up is described in Weinschel Engineering Application Note No. 4, a copy of which is included in this Instruction Manual. This set-up permits measurements to 20 db which can be repeated with a precision of .01 db per 10 db. The sensitivity and short-time stability permits the operator to estimate variations of .001 db. The system has an absolute accuracy of .02 db per 10 db when used with the recommended accessories. When used in a dual channel system, the gain of the BA-5 should be adjusted to produce a reading on the output indicator of approximately minus 7 db instead of full scale. This adjusts the proper level to the input of the Model ND-1, Differential Null Detector.

3.3 Extension of the Range of Measurement.

The maximum insertion loss that can be measured using either a single channel or a dual channel set-up is limited by noise at the low level and system non-linearity or available power at the high level. The system noise is an inherent characteristic of the system and is not under control of the operator, except insofar as careful set-up and

measurement techniques can reduce the hum pickup and other externally picked up noise to a minimum. However, certain of the non-linearities at the high level can be compensated for and, with certain precautions, an increased r.f. power level can be used.

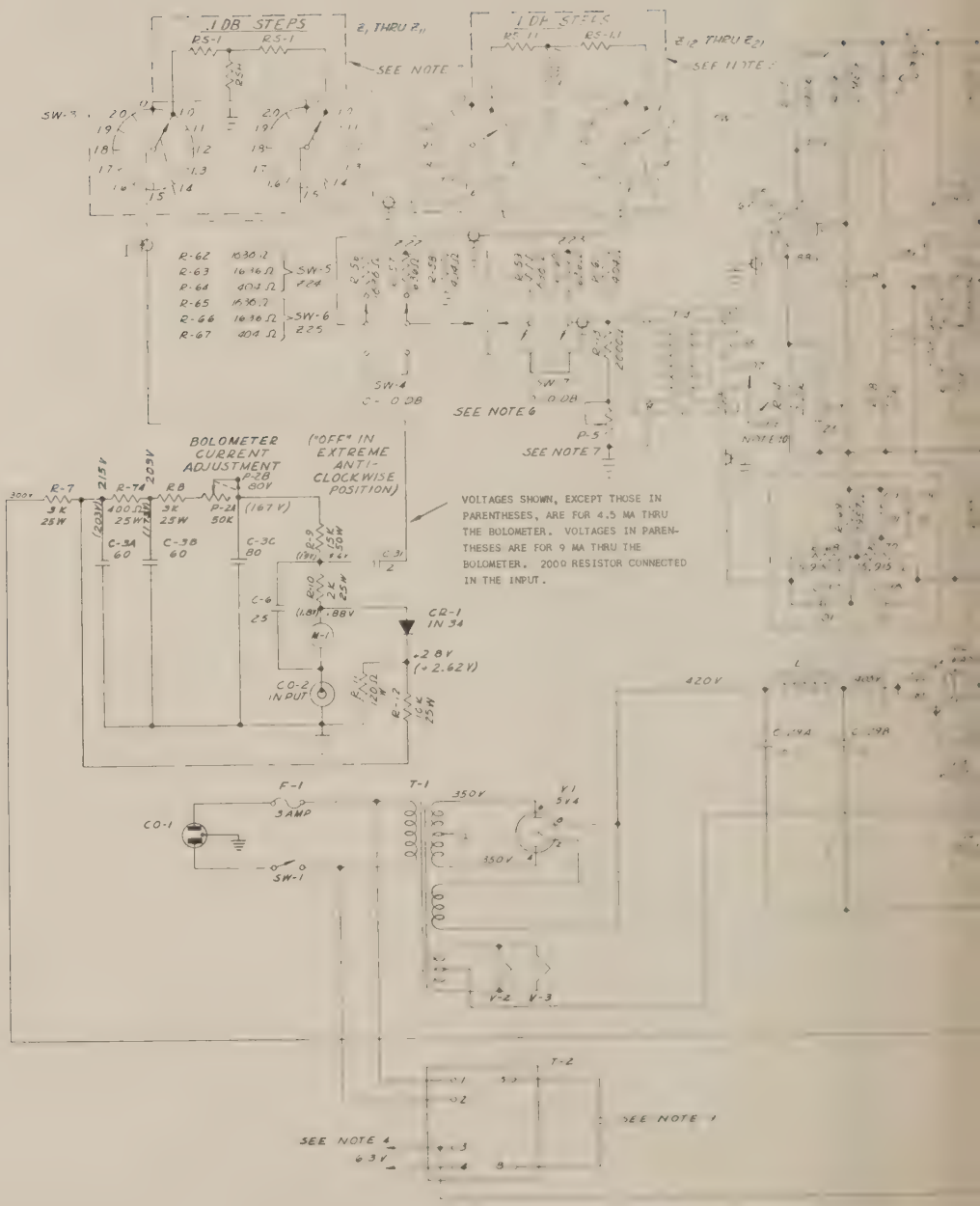
3.3.1 Partial RF Substitution: Reference is made to figure 5 and the block diagram on page 2 of Application Note No. 4. As normally used in both the single and dual channel set-ups, audio attenuation is substituted for r.f. attenuation in making a measurement. As explained above, due to the square law characteristic of the barretter, the substituted audio attenuation is twice the attenuation of the unit under test (all attenuation expressed in decibels). Therefore, to make a 20 db measurement, 40 db of substituted attenuation must be used. To reduce the amount of substituted audio attenuation for large attenuation measurements, it is possible to increase the r.f. power level used and, instead of substituting just audio attenuation, partial r.f. attenuation substitution can be used. For maximum accuracy, the attenuators used for r.f. substitution should be carefully calibrated on a dual channel set-up.

The technique is essentially the same for both dual and single channel set-ups but is more often used with a dual channel set-up because of the lower attenuation range covered. The measurement of 40 db of attenuation with a dual channel set-up will be used as an example. A 20 db attenuator is first calibrated using the dual channel set-up in the normal manner as outlined in Application Note No. 4.

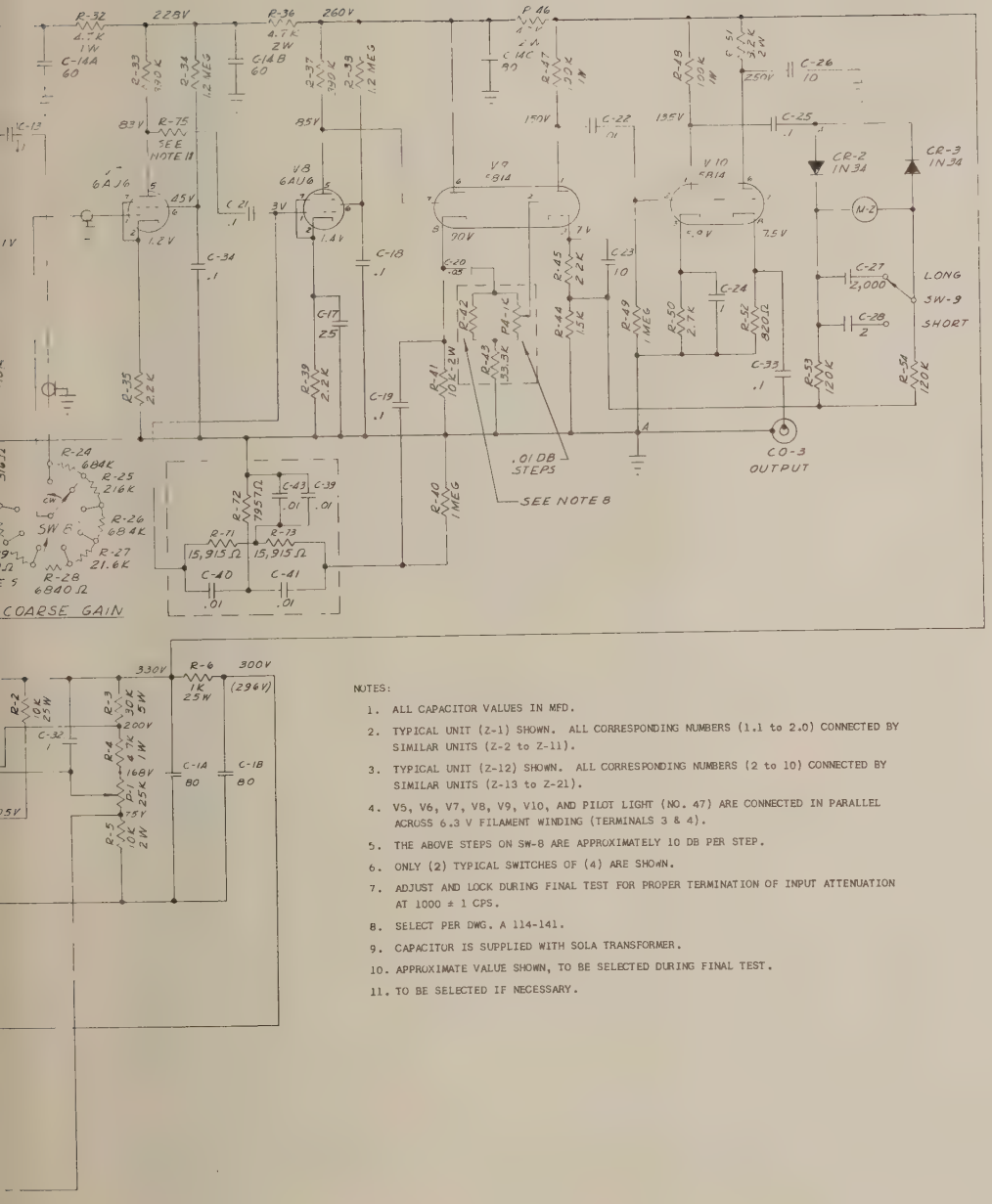
The power input to the system is then increased by means which will be discussed later so that with the standard 20 db pad in place of the unit under test, the proper input is applied to the Model BA-5 calibrator. The 20 db pad is then removed and the 40 db unit to be calibrated is put in the set-up. Audio attenuation is then removed to obtain a null on the Model ND-1 Differential Null Detector. The actual attenuation of the unit under test is then the difference in attenuation readings on the Model BA-5, plus the attenuation of the standard 20 db pad. Substantially the same procedure can be used with the single channel set-up.

To increase the power available from the source, it is possible with proper precautions to decrease the amount of padding used following the r.f. source. These precautions are necessary to assure constant output from the generator with any variations in load that might occur during a test. One very satisfactory way of doing this consists of sampling the incident power in the line at the generator output and using this signal to regulate the source output so as to keep the incident power constant regardless of load. Weinschel Engineering's modulated sources are equipped for this type of operation. A regulator circuit is provided to accept a signal from a directional coupler and maintain the generator incident power output constant over a wide range of load conditions. A little reflection will show that the maintenance of a constant incident power corresponds to a condition wherein the generator is properly matched to the line since any power reflected from the load back to the generator has no effect on the generator incident power output.

3.3.2 Use of a Barretter in Its Non-Linear Range: Up until now, it has been assumed that the barretter is a true square law device, i.e., the voltage output is proportional to the power input. Any error arising from non-linearity of the barretter characteristic will be less than .01 db as long as the power input to the barretter is less than approximately 200 microwatts. The maximum power varies somewhat with barretter type, but the foregoing is a reasonably good average figure. It is possible, however,


.1 DB STEPS
1 DB STEPS
SEE NOTE
SEE NOTE 6
SEE NOTE 7
SW-4
SW-5
SW-6
R-62 1030 Ω
R-63 1646 Ω
R-64 403 Ω
R-65 1030 Ω
R-66 1646 Ω
R-67 403 Ω
BOLOMETER CURRENT ADJUSTMENT
("OFF" IN EXTREME ANTI-CLOCKWISE POSITION)
VOLTAGES SHOWN, EXCEPT THOSE IN PARENTHESES, ARE FOR 4.5 MA THRU THE BOLOMETER. VOLTAGES IN PARENTHESES ARE FOR 9 MA THRU THE BOLOMETER. 2000 RESISTOR CONNECTED IN THE INPUT.
CR-1 IN 34
CO-2 INPUT
F-1 3 AMP
CO-1
SW-1
T-1
T-2
SEE NOTE 4
SEE NOTE 1
420 V
350 V

Figure



NOTES:

1. ALL CAPACITOR VALUES IN MFD.
2. TYPICAL UNIT (Z-1) SHOWN. ALL CORRESPONDING NUMBERS (1.1 to 2.0) CONNECTED BY SIMILAR UNITS (Z-2 to Z-11).
3. TYPICAL UNIT (Z-12) SHOWN. ALL CORRESPONDING NUMBERS (2 to 10) CONNECTED BY SIMILAR UNITS (Z-13 to Z-21).
4. V5, V6, V7, V8, V9, V10, AND PILOT LIGHT (NO. 47) ARE CONNECTED IN PARALLEL ACROSS 6.3 V FILAMENT WINDING (TERMINALS 3 & 4).
5. THE ABOVE STEPS ON SW-8 ARE APPROXIMATELY 10 DB PER STEP.
6. ONLY (2) TYPICAL SWITCHES OF (4) ARE SHOWN.
7. ADJUST AND LOCK DURING FINAL TEST FOR PROPER TERMINATION OF INPUT ATTENUATION AT 1000 ± 1 CPS.
8. SELECT PER DWG. A 114-141.
9. CAPACITOR IS SUPPLIED WITH SOLA TRANSFORMER.
10. APPROXIMATE VALUE SHOWN, TO BE SELECTED DURING FINAL TEST.
11. TO BE SELECTED IF NECESSARY.

hematic

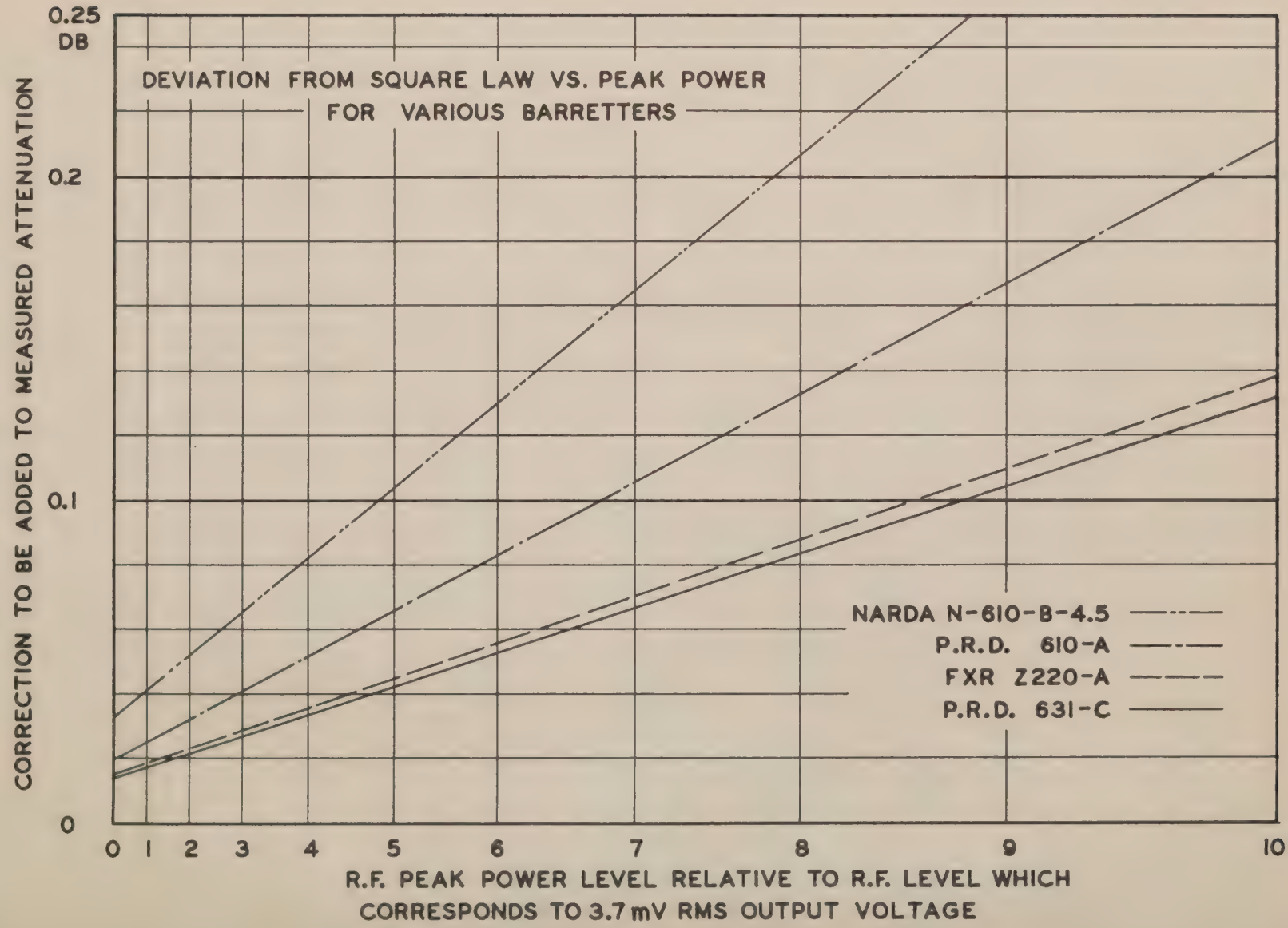

DEVIATION FROM SQUARE LAW VS. PEAK POWER
FOR VARIOUS BARRETTERS
CORRECTION TO BE ADDED TO MEASURED ATTENUATION
0.25 DB
0.2
0.1
0
NARDA N-610-B-4.5
P.R.D. 610-A
FXR Z220-A
P.R.D. 631-C
0 1 2 3 4 5 6 7 8 9 10 DB
R.F. PEAK POWER LEVEL RELATIVE TO R.F. LEVEL WHICH
CORRESPONDS TO 3.7 mV RMS OUTPUT VOLTAGE

Figure 7. Correction Curve for Barretters

to extend the range of the barretter by approximately 10 db if proper account is taken of the error so introduced. Figure 7 shows a correction curve to be used when the barretters are operated at high power levels.

In practice, enough audio attenuation is always used with the BA-5 to insure that the BA-5 amplifier is never overloaded. Enough r.f. power is then used so that a reasonable indication can be obtained on the BA-5 when the required amount of attenuation for the measurement to be made is in the circuit. The unit under test is then inserted and audio attenuation removed for the usual indication.

The indicated or measured attenuation will now be less than the actual attenuation of the unit under test due to the non-linearity of the barretter characteristic. The required correction can be obtained from figure 7, which correction must then be added to the measured value.

The correction is plotted against the peak r.f. power level into the barretter. This power level is expressed in decibels relative to the power required to produce a 1000 cycle output voltage of 3.7 millivolts. This presentation is used because it has been found that the output voltage, not the input power, is the controlling parameter. The reference level of 3.7 millivolts is used because it is approximately this voltage that will produce full scale deflection of the BA-5 output meter with the gain controls set to minimum and all attenuators set to zero. The setting of the BA-5 attenuators to produce full scale deflection with gain set to minimum will give the value with which to enter figure 7. The voltage at the barretter output can be verified by a simple voltage measurement at the BA-5 input.

SECTION 4

MAINTENANCE

4.1 Introduction.

Maintenance requirements for this equipment are very simple.

4.2 Scope of Procedure.

This document outlines the procedures to be followed in checking Attenuation Calibrator Model BA-5 for compliance with the original specifications (as guaranteed by the manufacturer at the time the equipment left the factory).

4.3 Operation and Use.

Operation and use of the equipment is covered in this instruction manual and Weinschel Engineering Application Note No. 4. Familiarity with the contents of these two documents is necessary before any servicing or recalibration is attempted.

4.4 Specifications

Performance specifications for Attenuation Calibrator Model BA-5 are given in Table I. In addition to checking for compliance with these specifications, several additional characteristics can be determined when performing the test procedures.

Table I. Performance Specifications

Power requirement:	105 to 125 volts, 60 cps
Audio frequency:	1000 ±3 cps
Audio frequency bandwidth:	Less than 35 cps between 3 db points
Voltage gain (approximate):	5×10^6 max. Approximately a 0.3 microvolt signal will produce full scale deflection on the output meter at full gain
Maximum output voltage:	1.5 volts rms to external indicator
Gain control range:	80 db
Equivalent noise:	Less than 30 millimicrovolts rms referred to the input when connected to a shielded 200 ohm wirewound resistor
Attenuator accuracy:	Better than 0.02 db for rf power ratios up to 30 db

The Attenuation Calibrator has been designed to require a minimum of maintenance. However, should trouble develop and servicing become necessary, the usual procedures for maintenance of vacuum tube amplifiers applies. With extremely high gain amplifiers, conditions of oscillations are occasionally encountered. In the Attenuation Calibrator, oscillation is indicated by a steady reading on the output meter, with or without a connection being made to the input jack. This unstable condition is usually caused by a high resistance or broken ground connection.

4.5 Procedures.

Attenuation Calibrator Model BA-5 is a combination instrument consisting of a dc bolometer bias supply, a variable precision audio frequency attenuator, a high gain 1 kc amplifier, and an indicator with its associated circuitry. Because of the very high gain, special testing precautions are required and care must be taken in the interpretation of the results obtained from the tests. Since the Attenuation Calibrator is designed for use with square law detectors, all decibel scales are in terms of rf power level ratios at the detector input. To convert to af power level ratios, the readings must be doubled.

4.5.1 Test Equipment Required: The test equipment, cables and connectors required to perform the compliance test procedures are given in Tables II, III and IV.

4.5.2 Tubes: The checks usually made to determine the condition of vacuum tubes will normally suffice. The test described in 4.6.7 below should be made if excessive noise originating from tube trouble is suspected.

4.5.3 Components: Resistance, capacitance and voltage values are shown in the schematic diagram, figure 6. Voltage measurements were made using a 20,000 ohms per volt meter.

Table II. Test Equipment Required

Nomenclature	Model No.	Application	Range	Accuracy
Audio Oscillator (Hewlett-Packard Co.)	200CD	Variable oscillator	5 cps to 600 kc	
Universal Counter (Berkeley)	5510	Electronic counting	DC to 1,000,000 cps	± Crystal stability
Audio Attenuator (General Radio)	1450-TA	Variable attenuation	0 to 100 db in 10 db steps; 0 to 10 db in 1 db steps	± 0.005 db
Variac (General Radio)	W2	Line voltage control	0 to 130 volts at 2 amperes	±3 percent
Audio Vacuum Tube Voltmeter (Instrument Electronics Co.)	247	Measurement of ac voltages	0.5 mv to 500 volts rms	±1 percent
Volt - Ohm Meter (Simpson) (2 required)	262	Measurement of ac and dc voltages	0 to 400 vdc; 0 to 160 vac	
Minimum Loss Pad*		Impedance matching		
200 Ohm Shielded Wirewound Resistor (Weinschel Engineering Co.)	699	Termination		

* Necessary to manufacture locally. See Figure 9.

4.5.4 Input Termination: UNDER NO CIRCUMSTANCES SHALL PRE-SET POTENTIOMETER BE ADJUSTED. This is adjusted and locked at the factory during final testing to provide a correct 2000 ohm termination for the precision input attenuator. Any change of its setting will cause errors in the calibration of the attenuator and necessitate its being returned to the factory for re-setting.

4.6 Performance Tests

The following tests are designed to indicate whether or not the equipment meets the specifications to which it has been guaranteed. Unless otherwise directed, set the following controls on the Attenuation Calibrator to the positions indicated prior to starting each test:

Table III. Cables Required

Cable No.	Wire Type	Connectors	Length
1	RG-58A/U	UG88/U to UG88/U	3 feet
2	RG-58A/U	UG88/U to GR type 274NK	3 feet
3	RG-58A/U	UG88/U to GR Type 274NK	3 feet
4	RG-58A/U	UG88/U to GR Type 274NK	3 feet
5	RG-58A/U	GR Type 274NK to GR Type 274NK	1 foot

Table IV. Connectors Required

Quantity	Type
2	UG-274A/U

Control	Position
METER TIME CONSTANT switch	SHORT
BOLOMETER CURRENT ADJUST	OFF (extreme counterclockwise)
ON - OFF toggle switch	ON

Also prior to starting each test, set the line input voltage to the Attenuation Calibrator to 117 vac by adjusting the Variac.

NOTE

For purposes of impedance matching, audio attenuator No. 2 should have a minimum of 20 db of attenuation inserted at all times. (See Figure 8).

4.6.1 Power Supply Voltage Adjustment: Apply primary power to the Attenuation Calibrator. Connect one volt-ohm meter, set on the 0-160 vac scale, across the line input terminals of the Attenuation Calibrator to monitor the ac line voltage. Connect the second volt-ohm meter, set on the 0-400 vdc scale, across capacitor C-1A to monitor the B plus voltage. Adjust potentiometer P-1 until the voltage across C-1A is 330 vdc when the line voltage is set to 117 vac.

Vary the line voltage by means of the Variac over the range of 105 to 130 vac. The change in voltage across C-1A should be less than one percent. Reset the Variac to 117 vac.

4.6.2 Center Frequency: Connect the equipment as shown on Figure 8. Set the COARSE and FINE GAIN controls on the Attenuation Calibrator to zero, and the audio oscillator frequency to approximately 1000 cps. Adjust the audio oscillator and audio attenuators to obtain a convenient output meter reading on the Attenuation Calibrator. Adjust the audio oscillator frequency for maximum output meter deflection. If necessary, readjust the audio oscillator output level to prevent driving the Attenuation

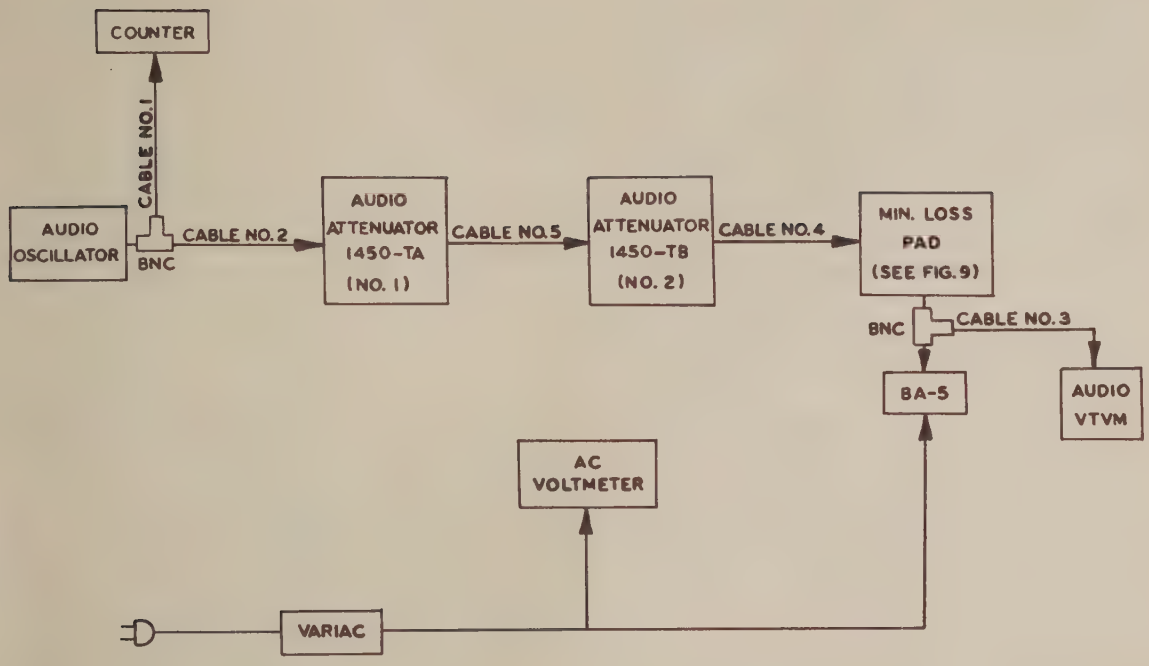


Figure 8. General Performance Test, Test Equipment Set-Up

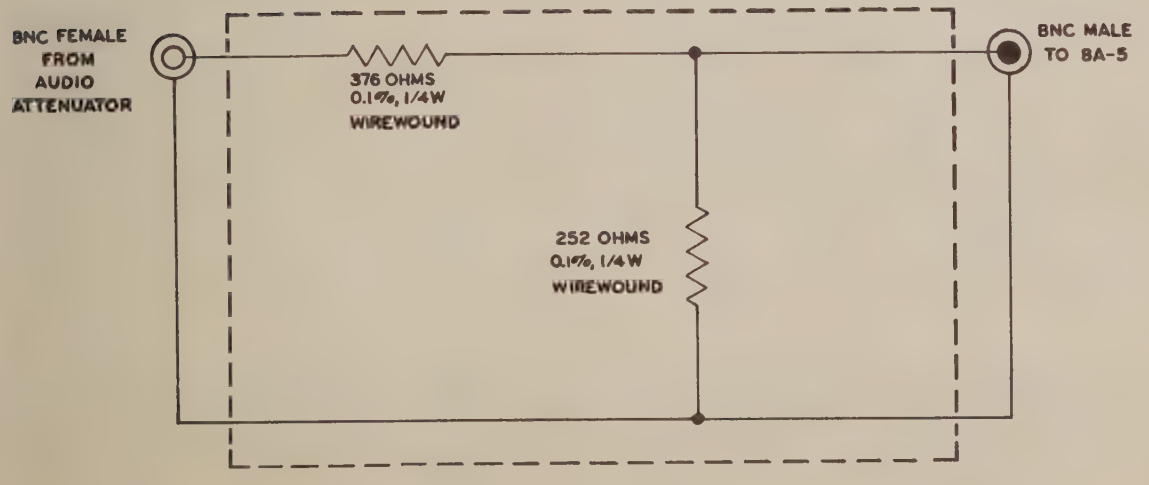


Figure 9. Minimum Loss Pad

Calibrator output meter off scale. The audio oscillator frequency should be 1000 ±3 cps as measured with the Universal Counter.

4.6.3 Bandwidth: Connect the equipment as shown on Figure 8. On the Attenuation Calibrator, leave the COARSE and FINE GAIN controls maximum counterclockwise and the attenuator controls at zero. Adjust the audio oscillator frequency for maximum output meter deflection on the Attenuation Calibrator; then adjust the audio level until the output meter reads full scale or 0 db. Increase the audio frequency until the output meter reads 1.5 db. Measure and record this frequency. Decrease the audio frequency until the Attenuation Calibrator output meter passes through a maximum and again decreases to a reading of 1.5 db. Measure and record this frequency. The difference between the two recorded frequencies should be less than 35 cps. Note that 1.5 db as indicated on the meter corresponds to 3 db at the audio frequency.

Vary the audio frequency from 900 to 1100 cps. The output meter indication should go through a single maximum deflection.

4.6.4 Voltage Gain: Connect the equipment as shown on Figure 8. Set audio attenuator No. 1 to 20 db and audio attenuator No. 2 to 40 db. With the audio oscillator frequency adjusted to produce maximum output meter deflection on the Attenuation Calibrator, adjust the output level of the audio oscillator to produce an input voltage level of 1 millivolt to the Attenuation Calibrator. Set audio attenuator No. 1 to 90 db. On the Attenuation Calibrator, leave all attenuators set at zero and set the COARSE and FINE GAIN controls maximum clockwise. Adjust audio attenuator No. 1 to produce full scale deflection on the Attenuation Calibrator output meter. This should occur at a setting between 88 and 94 db. Then decrease the gain of the Attenuation Calibrator to minimum (COARSE and FINE GAIN controls maximum counterclockwise) and again decrease the attenuation of audio attenuator No. 1 to 20 db. Move the vacuum tube voltmeter from the input to the OUTPUT connector of the Attenuation Calibrator. With the signal adjusted for full scale output meter deflection, the voltage at the OUTPUT connector should be 1.5 ± 0.3 volts.

4.6.5 Gain Control Range: With the equipment connected as shown on Figure 8, set the GAIN controls on the Attenuation Calibrator maximum clockwise, the attenuators on the Attenuation Calibrator to zero, audio attenuator No. 1 to 90 db, audio attenuator No. 2 to 40 db, and the audio oscillator output to produce full scale deflection on the Attenuation Calibrator output meter. Reduce the gain of the Attenuation Calibrator to minimum and then remove attenuation from audio attenuator No. 1 until the output meter again reads full scale deflection. Audio attenuator No. 1 should have no more than 10 db of attenuation remaining.

4.6.6 Attenuator Accuracy:

NOTE

> It is necessary to use an af signal generator with a very stable output for the following test procedure since any change in signal generator output level will show up as an error in the attenuator accuracy.

With the equipment connected as shown on Figure 8, insert 40 db of attenuation into audio attenuator No. 1 and 44 db of attenuation into audio attenuator No. 2. On the Attenuation Calibrator, rotate the COARSE GAIN control clockwise to its second

position and set the FINE GAIN control to mid-range. At the audio oscillator, adjust the frequency to 1000.0 cps and the output level to provide a 0.3 mv input to the Attenuation Callibrator. On the Attenuation Calibrator, set all attenuators to zero and adjust the FINE GAIN control for an output meter reference reading of 1.3 db. Now set one 0-10 DB R.F. toggle switch to its 10 DB R.F. position and remove 20 db from attenuator No. 1. The output meter on the Attenuation Calibrator should return to its original reading. Should the meter reading be off, adjust potentiometer P-5 to correct the meter reading. Insert 20 db of attenuation in audio attenuator No. 1 and remove the 10 db of attenuation inserted in the Attenuation Calibrator. Adjust the FINE GAIN control for a 1.3 db output meter reading. This procedure should be repeated several times until a meter reference reading of exactly 1.3 db is obtained for this 10 db rf insertion loss measurement. Then proceed by inserting 20 db of attenuation in the Attenuation Calibrator, using two 0-10 DB R.F. toggle switches set to their 10 DB R.F. positions, and removing 40 db of attenuation from audio attenuator No. 1. Now switch the 0 to 10 DB R.F. selector switch to the 10 DB R.F. position and remove 20 db of attenuation from audio attenuator No. 2. The total deviation for this 30 db rf insertion loss measurement should not exceed $\pm$0.02 db.

NOTE

Make sure that all cables are well shielded and all equipment is well grounded since any ground circuits or circuit loops will cause an error.

Repeat this procedure for checking the 0 to 2 and -.01 to .11 DB R.F. vernier selector switches on the Attenuation Calibrator keeping in mind that the audio attenuation removed from the audio attenuators must be equal to twice the rf attenuation inserted in the Attenuation Calibrator to return the output meter reading to the reference value. The remaining 0-10 DB R.F. toggle switches may be checked by inserting them one at a time into the line and switching the one that is already in the line to its 0 position.

4.6.7 Internal Noise: Connect the equipment as shown on Figure 10. On the Attenuation Calibrator, set all attenuators to zero and GAIN controls maximum clockwise. The output voltage as read on the audio vacuum tube voltmeter should be less than 150 millivolts. This output voltage should be independent of the setting of the BOLOMETER CURRENT ADJUST. Care should be exercised in making this measurement to be certain that the 200 ohm resistor connected to the Attenuation Calibrator input is well shielded. The resistor must be wirewound since a composition resistor can introduce an appreciable amount of noise. The audio vtvm must be connected to the OUTPUT connector of the Attenuation Calibrator by means of a shielded cable to prevent pick-up of undesired signals in the leads. Also make sure that no strong magnetic fields (such as those originating from heavy motors, etc.) are present since they might contribute excessive hum signals which would show up as noise.

4.6.8 Selective Feedback Networks: Two twin-tee networks are used in feedback circuits to determine the amplifier bandwidth. The bandwidth between 3 db points should be approximately 35 cps centered at 1000 cps. If either the bandwidth or center frequency is found to be outside of the specifications and the trouble is isolated to one of the twin-tee networks, the equipment should be returned to the factory for repair.

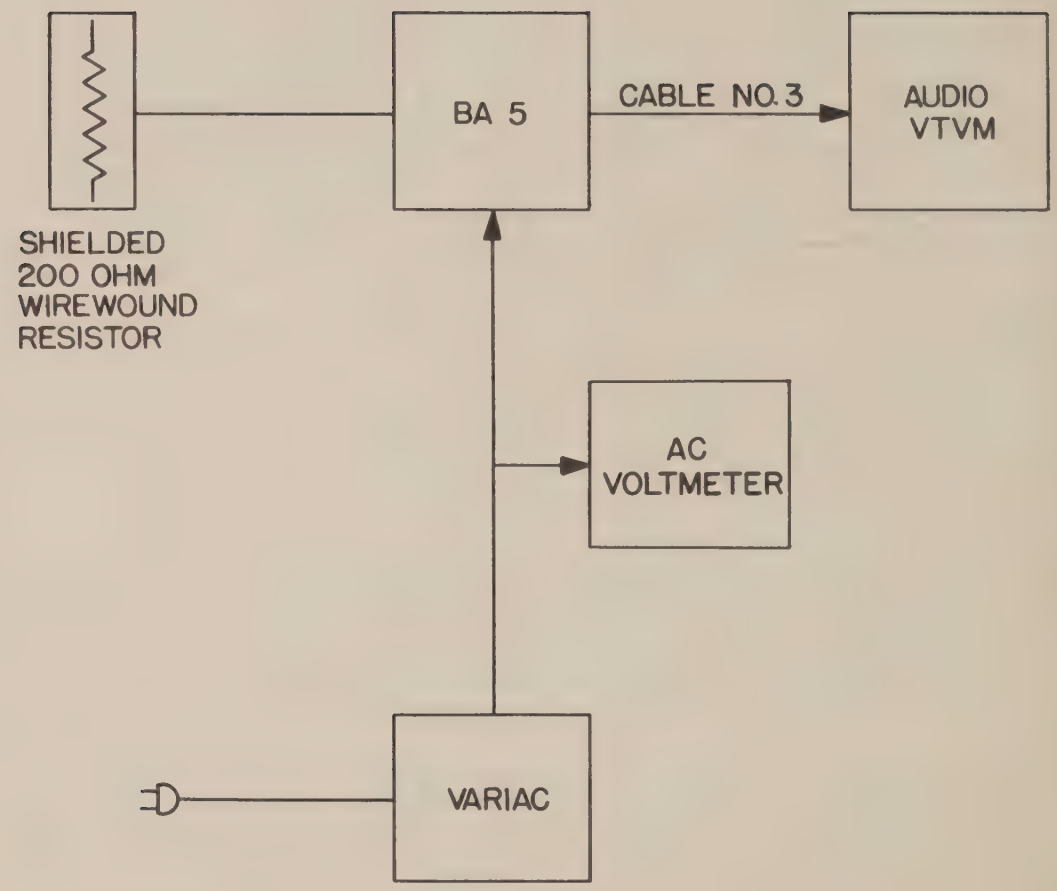


Figure 10. Noise, Test Equipment Set-Up

SCHEMATIC SYMBOL	DESCRIPTION	WECO PART NO.
C1A,B	Capacitor, Elect, 2 Section, 80/80 mfd, 350V	32-9
C2	Not Used	
C3,A,B,C	Capacitor, Elect, 3 Section 60/60/80 mfd, 350V	32-10
C4	Not Used	
C5	Not Used	
C6	Capacitor, Elect, 25 mfd, 50V	31-4
C7	Same as C6	
C8	Capacitor, Molded paper, .1 mfd, 400V	33-2-R1
C9	Capacitor, Elect, 2 mfd, 450V	31-12
C10	Same as C8	
C11	Capacitor, Molded paper, .05 mfd, 400V	33-2-R05
C12	Same as C11	
C13	Same as C8	
C14A,B,C	Same as C3	
C15	Not Used	
C16	Not Used	
C17	Same as C6	
C18	Same as C8	
C19	Same as C8	
C20	Same as C11	
C21	Same as C8	
C22	Capacitor, Molded paper, .01 mfd, 400V	33-2-R01
C23	Capacitor, Elect, 10 mfd, 50V	31-3
C24	Capacitor, Met. paper, 1 mfd, 200V	33-6-1
C25	Same as C8	
C26	Capacitor, Elect, 10 mfd, 450V	31-5
C27	Capacitor, Elect, 2000 mfd, 6V	31-1
C28	Capacitor, Met. paper, 2 mfd, 200V	33-6-2
C29	Capacitor, Elect, 10/10 mfd, 450V	32-11
C30	Not Used	
C31	Capacitor, Paper, bathtub type, 2 mfd, 600V	35-1
C32	Capacitor, Paper, bathtub type, 1 mfd, 400V	35-14
C33	Same as C8	

SCHEMATIC SYMBOL	DESCRIPTION	WECO PART NO.
C34	Same as C8	
C35	Capacitor, Silver mica, To be selected: approx. value .0007 mfd	
C36	Capacitor, Silver mica, .01 mfd, 300V	34-2-R01
C37	Same as C36	
C38	Same as C36	
C39	Same as C36	
C40	Same as C36	
C41	Same as C36	
C42	Same as C36	
C43	Same as C36	
C01	Connector, male, AC line, 3-Pin Motor Base	62-38
C02	Connector, Coaxial, UG-928/U	63-14
C03	Same as C02	
CR1	Diode, Crystal, IN34	12-1
CR2	Same as CR1	
CR3	Same as CR1	
F1	Fuse, 3 amperes	52-1-3
L1	Choke, Filter	40-66
M1	Meter, 0-10 MADC	16-1
M2	Meter, 0-200 μADC, VSWR	A114-117
P1	Resistor, Variable, W/W 25K, 2W	20-9
P2	Resistor, Variable, W/W, 50K ohms, 4W	20-44
P3	Resistor, Variable, W/W, 15K/3K, 3W	20-10
P4	Resistor, Variable, W/W, 1K, 4W	20-54
P5	Resistor, Variable, W/W, 2K, 4W	20-43
R1	Resistor, Comp, 3.3 Megohms, 10%, 1W	25-2-3R3M
R2	Resistor, Wirewound, 10K ohms, 5%, 25W	26-8-10K
R3	Resistor, Wirewound, 28K ohms, 5%, 5W	26-6-28K
R4	Resistor, Comp, 4.7K ohms, 10%, 1W	25-2-4700
R5	Resistor, Comp, 10K ohms, 10%, 2W	25-3-10K
R6	Resistor, Wirewound, 1K ohms, 5%, 25W	26-8-1000
R7	Resistor, Wirewound, 3K ohms, 5%, 25W	26-8-3000
R8	Same as R7	

SCHEMATIC SYMBOL	DESCRIPTION	WECO PART NO.
R9	Resistor, Wirewound, 15K ohms, 5%, 50W	26-9-15K
R10	Resistor, Wirewound, 2K ohms, 5%, 25W	26-8-2000
R11	Resistor, Comp, 120 ohms, 10%, 1W	25-2-120
R12	Same as R2	
R13	Resistor, Comp, 2K ohms, 1%, 1/2W	26-2-2000
R14	Resistor, Comp, 2.2K ohms 10%, 1/2W	25-1-2200
R15	Resistor, Comp, 390K ohms, 10%, 1/2W	25-1-390K
R16	Resistor, Comp, 1.2 Megohms, 10%, 1/2W	25-1-1R2M
R17	Resistor, Comp, 68K ohms, 10%, 1W	25-2-68K
R18	Resistor, Comp, 10K ohms, 10%, 1/2W	25-1-10K
R19	Resistor, Comp, 7.5K ohms, 5%, 1/2W	25-8-7500
R20	Resistor, Comp, 47K ohms, 10%, 1/2W	25-47K
R21	Same as R18	
R22	Resistor, Comp, 2.2 Megohms, 10%, 1/2W	25-1-2R2M
R23	Resistor, Comp, 100K ohms, 10%, 1/2W	25-1-100K
R24	Resistor, Film, 684K ohms, 1%, 1/3W	25-13-684K
R25	Resistor, Film, 216K ohms, 1%, 1/3W	25-13-216K
R26	Resistor, Film, 68.4K ohms, 1%, 1/3W	25-13-68440
R27	Resistor, Film, 21.6K ohms, 1%, 1/3W	25-13-21600
R28	Resistor, Film, 6840 ohms, 1%, 1/3W	25-13-6840
R29	Resistor, Film, 2160 ohms, 1%, 1/3W	25-13-2160
R30	Resistor, Film, 684 ohms, 1%, 1/3W	25-13-684
R31	Resistor, Film, 316 ohms, 1%, 1/3W	25-13-316
R32	Same as R4	
R33	Same as R15	
R34	Same as R16	
R35	Same as R14	
R36	Resistor, Comp, 4.7K ohms, 10%, 2W	25-3-4700
R37	Same as R15	
R38	Same as R16	
R39	Same as R14	
R40	Resistor, Comp, 1 Megohms, 10%, 1/2W	25-1-1M
R41	Same as R5	
R42	Resistor (to be selected per drawing A114-141)	

SCHEMATIC SYMBOL	DESCRIPTION	WECO PART NO.
R43	Resistor, Wirewound, 33.3K ohms, 1%, 1/2W	25-4-33300
R44	Resistor, Comp, 1.5K ohms, 10%, 1/2W	25-1-1500
R45	Same as R14	
R46	Same as R36	
R47	Resistor, Comp, 100K ohms, 10%, 1W	25-2-100K
R48	Same as R47	
R49	Same as R40	
R50	Resistor, Comp, 2.7K ohms, 10%, 1/2W	25-1-2700
R51	Resistor, Comp, 8.2K ohms, 10%, 2W	25-3-8200
R52	Resistor, Comp, 820 ohms, 10%, 1/2W	25-1-820
R53	Resistor, Comp, 120K ohms, 10%, 1/2W	25-1-120K
R54	Same as R53	
R55	Same as R40	
R56 through R67	Part of Z22, Z23, Z24, Z25	
R68	Resistor, Wirewound, 15,915 ohms, .1%, 1/2W	26-2-15915
R69	Resistor, Wirewound, 7957 ohms, .1%, 1/2W	26-2-7957
R70	Same as R68	
R71	Same as R68	
R72	Same as R69	
R73	Same as R68	
R74	Resistor, Wirewound, 400 ohms, 5%, 25W	26-8-400
SW1	Switch, Toggle, SPST	55-1
SW2	Switch, 2 Pole, 12 Position	56-3
SW3	Same as SW2	
SW4	Switch, Lever, DPDT	57-4
SW5	Same as SW4	
SW6	Same as SW4	
SW7	Same as SW4	
SW8	Switch, Rotary, 1 Pole, 11 Position	56-1
SW9	Switch, Toggle, 2 Circuit, 2 Position	55-2
T1	Transformer, Power, Plate & Fil.	40-8
T2	Transformer, with capacitor 1010-5, Fil., .5 mfd.	40-2

SCHEMATIC SYMBOL	DESCRIPTION	WECO PART NO.
T3	Not Used	
T4	Transformer, Input	40-47
V1	Tube, Electron, 5V4	10-1
V2	Tube, Electron, 6AS7	10-3
V3	Tube, Electron, 6SJ7	10-4
V4	Tube, Electron, OC3	10-5
V5	Tube, Electron, 6AU6	10-2
V6	Tube, Electron, 5814	10-7
V7	Same as V5	
V8	Same as V5	
V9	Same as V6	
V10	Same as V6	
Z1	Network, Attenuation, (Consists of 2 series and one shunt resistor)	26-24-1
Z2	" " "	26-24-2
Z3	" " "	26-24-3
Z4	" " "	26-24-4
Z5	" " "	26-24-5
Z6	" " "	26-24-6
Z7	" " "	26-24-7
Z8	" " "	26-24-8
Z9	" " "	26-24-9
Z10	" " "	26-24-10
Z11	" " "	26-24-11
Z12	Same as Z1	
Z13	Same as Z11	
Z14	Network, Attenuation, (Consists of 2 series and one shunt resistor)	26-24-12
Z15	" " "	26-24-13
Z16	" " "	26-24-14
Z17	" " "	26-24-15
Z18	" " "	26-24-16
Z19	" " "	26-24-17
Z20	" " "	26-24-18
Z21	" " "	26-24-19
Z22 through Z25	Same as Z21	

WARRANTY

WEINSCHEL Engineering warrants each instrument of its manufacture to be free from defects in material and workmanship. Our obligation under this warrant is limited to servicing or adjusting any instrument returned to our factory for that purpose, and to making good at our factory any part or parts thereof (except tubes, fuses, or batteries) which shall, within one year after making delivery to the original purchaser, be returned to us with transportation charges prepaid, and which on our examination shall disclose to our satisfaction to have been defective.

Weinschel Engineering reserves the right to make changes in design at any time without incurring any obligation to install same on units previously purchased.

This warranty is expressly in lieu of all other obligations or liabilities on the part of Weinschel Engineering.

Weinschel Engineering neither assumes nor authorizes any other person to assume for them any other liability in connection with the sale of their instruments and equipment.

Calibration standards as applicable are
traceable to the National Bureau of Standards.

Application Note No. 4

DUAL CHANNEL INSERTION LOSS TEST SET

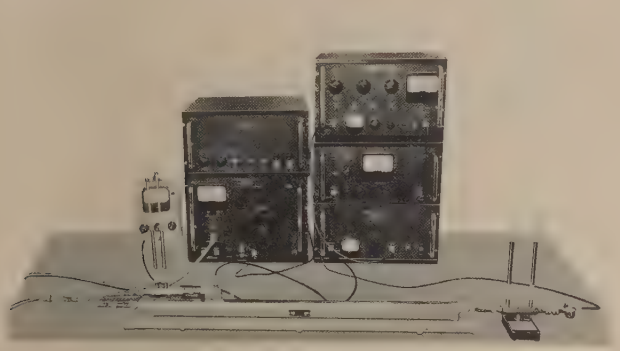
Introduction

The determination of the insertion loss of cable assemblies, r-f switches, the calibration of precision attenuators and similar precision insertion loss measurements requires a precise measurement of r-f power ratios.

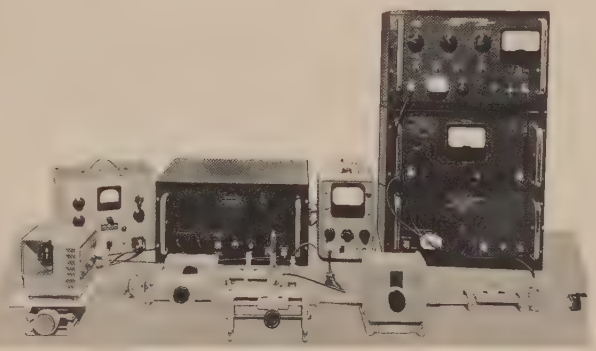
A very useful method of making such measurements uses a square wave modulated r-f source, square law detector and audio substitution attenuator as described in WECO Application Note No. 1. (1)* In this method, audio attenuation is substituted for r-f attenuation so as to maintain a constant audio output. In theory at least, it is only necessary to increase the sensitivity of the indicator to increase the precision of the measurement, providing all elements in the system have the required stability. It is this stability requirement that limits the precision that can be obtained with the system described in Application Note No. 1. (1) In particular, drift in the output level of the r-f source during the time required to substitute the unknown in the setup limits the precision attainable with that method.

To overcome this source of error, Weinschel Engineering has developed a Differential Null Detector, which, when used with the recommended accessories, permits measurements to 20 db which can be repeated with a precision of .01 db per 10 db. The sensitivity and short time stability permits the operator to estimate variations of .001 db. The system has an absolute accuracy of .02 db per 10 db when used with the recommended accessories. This instrument and the method of measurement are the subjects of this application note.

** Numbers in () refer to items in the bibliography at the end of this application note.*



Coaxial



Waveguide

The Dual Channel Insertion Loss Test Set

The Method

A stable radio frequency source of the proper frequency is 100% square wave modulated at a frequency of 1 kilocycle and is divided into two channels: the measurement channel and the reference channel. The two r-f signals derived from the same generator are detected in two bolometers which are operated in their square law region, i.e., the voltage at the modulation frequency (i.e. 1000 cycles per second) developed across the bolometer is proportional to the r-f power absorbed by the bolometer. (2, 3) It is important that the bolometers be properly matched to the r-f line either by the use of transmission line tuners or the use of a broad band mount and that they not be driven out of the square law region. The 1 kc signals from the bolometers are then amplified and applied to the Differential Null Detector, Model ND-1.

The location of the various units in the system and their function can be understood by reference to the following explanation and the block diagram. Following the bolometer in the reference channel is Bolometer Preamplifier, Model BA-1 that serves to supply to the Differential Null Detector a 1 kc voltage with an amplitude that is accurately proportional to the power output of the r-f signal source. The measurement channel contains a slotted line, provisions for insertion of the unit under test, a bolometer mount and an Attenuation Calibrator, Model BA-5. The output of the BA-5 is applied to the other input of the Differential Null Detector. The BA-5 contains a precision audio substitution attenuator followed by a linear 1 kc amplifier. In making an insertion loss measurement,audio attenuation is substituted for the attenuation of the unit under test.

To measure insertion loss, the precision audio substitution attenuator in the BA-5 Attenuation Calibrator is first set to include at least slightly more at-

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tenuation than the expected insertion loss of the unit to be tested or calibrated. The gain in the reference channel and the phasing adjustments on the Differential Null Detector, ND-1 are adjusted to produce a null reading on the ND-1. The unit under test is then inserted in the measurement channel as shown in the block diagram. Audio attenuation is removed until a null indication on the ND-1 is again obtained. The amount of audio attenuation removed is a measure of the insertion loss of the unit under test. It will be noted that the output of the measurement channel is not necessarily returned to the same level as before insertion of the unit under test, but rather to a value to produce a null reading on the ND-1. If the r-f source output has drifted since the first null adjustment, the reference channel output has changed by a proportionate amount and the measurement channel output required to produce a null is automatically compensated.

The design of the Differential Null Detector is such that the front panel indicator displays a highly non-linear behavior. If the two inputs to the ND-1 are very different, the amplifier in the ND-1 assumes approximately a logarithmic characteristic and the meter is not driven off scale. As the signal level is adjusted to produce a null indication, the proper direction of the adjustment can be determined and as the null is approached the sensitivity of the indication automatically increases to allow a precise adjustment to be made.

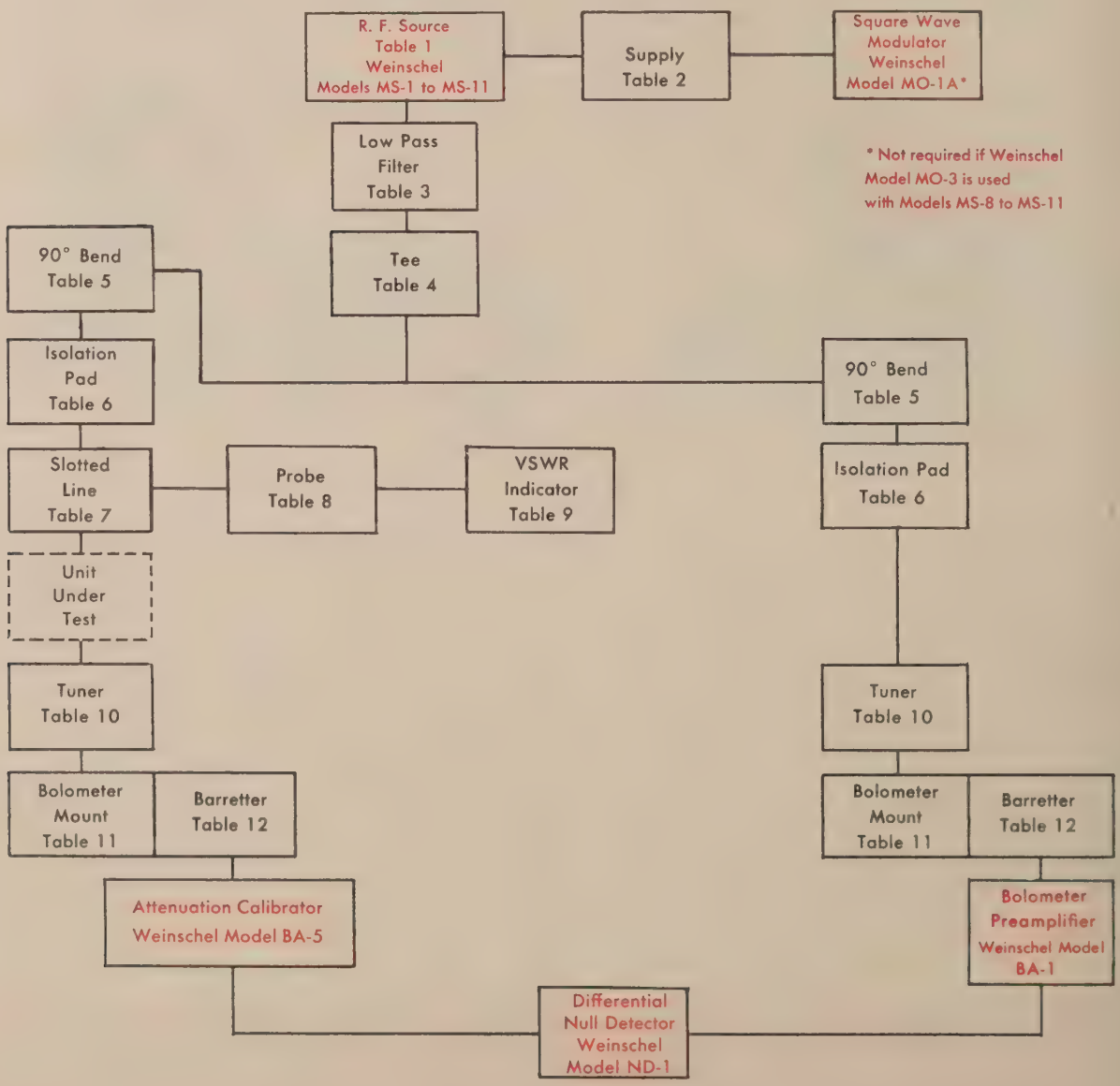
R. F. Source Table 1 Weinschel Models MS-1 to MS-11
Supply Table 2
Square Wave Modulator Weinschel Model MO-1A*
* Not required if Weinschel Model MO-3 is used with Models MS-8 to MS-11
Low Pass Filter Table 3
Tee Table 4
90° Bend Table 5
Isolation Pad Table 6
Slotted Line Table 7
Probe Table 8
VSWR Indicator Table 9
Unit Under Test
Tuner Table 10
Bolometer Mount Table 11
Barretter Table 12
Attenuation Calibrator Weinschel Model BA-5
90° Bend Table 5
Isolation Pad Table 6
Tuner Table 10
Bolometer Mount Table 11
Barretter Table 12
Bolometer Preamplifier Weinschel Model BA-1
Differential Null Detector Weinschel Model ND-1

TABLE 1 R.F. SOURCES

Frequency Range kmcs	Manufacturer	Model Number	Power Supply Required
0.05 – 0.25	Weinschel	MS-1	None
0.25 – 0.92	Weinschel	MS-2	None
0.90 – 2.00	Weinschel	MS-3	None
0.90 – 2.20	Weinschel	MS-8	Weinschel Model MO-3*
1.20 – 3.75	Raytheon	2-K-28	See Table 2
1.99 – 2.10	Varian	X-17	"
2.00 – 4.20	Weinschel	MS-4	None
2.00 – 4.20	Weinschel	MS-9	Weinschel Model MO-3*
2.66 – 3.31	Sperry	2-K 41	See Table 2
3.3 – 4.20	Sperry	2-K 42	"
4.0 – 7.30	Weinschel	MS-5	None
4.0 – 7.30	Weinschel	MS 10	Weinschel Model MO-3*
4.2 – 5.70	Sperry	2-K 43	See Table 2
5.7 – 7.50	Sperry	2-K 44	"
7.2 – 10.50	Weinschel	MS-6	None
7.2 – 10.50	Weinschel	MS-11	Weinschel Model MO-3*
7.5 – 10.3	Sperry	2-K 39	See Table 2
8.2 – 12.4	Varian	X-13	"
10.0 – 15.0	Varian	V-39-C	See Table 2
12.4 – 17.5	Varian	X-12	"
15.0 – 21.0	Varian	V-40-C	"
22.0 – 25.0	Raytheon	233	"
22.0 – 25.0	Varian	VA-96	"
26.3 – 31.3	Raytheon	QK-140	"
30.0 – 35.3	Raytheon	QK-141	"
33.0 – 37.5	Raytheon	QK-141	"
33.5 – 36.2	Raytheon	QK-291	"
34.0 – 35.6	Varian	VA-97	"
34.9 – 40.6	Raytheon	QK-142	"
37.5 – 44.1	Raytheon	QK-226	"
41.7 – 50.0	Raytheon	QK-294	"
50.0 – 60.0	Raytheon	QK-295	"

* Includes Modulator

TABLE 2
KLYSTRON POWER SUPPLIES

PRD	801-A
Sperry	SX-12
FXR	Z815A

The Instruments

The r-f power source must be stable in both frequency and output level so that no change in the characteristics of the unit under test will occur during the measurement. The use of the dual channel setup reduces the effect of any change in the source output insofar as the measuring equipment is concerned but if the unit under test is non-linear, its characteristics may change. The same considerations apply with regard to frequency variations, except that if the impedance characteristics of the bolometers are not the same, and in general they are not, a small change in frequency can result in an appreciable variation in the balance between the two channels.

The r-f power sources must be 100% square wave modulated at a frequency of 1000 cycles per second. It is important that this frequency be very stable, since the elements in both channels of the setup are tuned to this frequency and at the center of the band the phase characteristic has its greatest slope. A very small change in modulation frequency can, therefore, result in a large change in the phase of the signal applied to the Differential Null Detector. For the two signals applied to the inputs of the Differential Null Detector to produce a null, not only must their amplitudes be equal, but they must be properly phased. A small change in the modulation frequency will in general result in an appreciable change in the relative phase between the signals from the two channels. It is recommended that Weinschel Engineering's Model MO-1A Modulator be used in this application. It supplies a square wave, at a frequency of 1000 ± 0.1 cycles per second that is derived from a tuning fork oscillator. The amplitude is sufficient to fully modulate most test oscillators and klystrons.

Both channels have a pad immediately following the divider to insure a constant source impedance and prevent any reaction between the generator and the unit under test or between channels.

The linear range of the reference channel is not critical since it operates at a substantially constant level throughout the measurement. Convenience, however, dictates a fairly wide dynamic range and a variable gain to allow easy adjustment of the signal level at the output of the reference channel. It is also necessary that the gain of this channel be very stable. Weinschel Engineering's Model BA-1 Amplifier fulfills these requirements.

The measurement channel is similar to the system

TABLE 3
LOW PASS FILTERS

Cutoff Frequency kmcs	Manufacturer	Model Number
.044	Sierra	184
.076	Sierra	184
.135	Sierra	184
.230	Sierra	184
.400 .5	Sierra/NARDA	184 3010-500
.400	Bird	844
.7-1.0	H.P./NARDA	360-A/3010-1000
1.2	Bird	819-1200
1.2	H.P.	360-B
2.2 2.1	H.P. NARDA	360-C/3010-2100
4.1 4.2	H.P. NARDA	360-D 3010-4200

TABLE 4
TEES
COAXIAL
UG-28A/U
UG-107A/U, B/U
WAVEGUIDE—SHUNT TYPE—H-PLANE

Frequency Range, kmc	Manufacturer's Model Number		
	FXR	Narda	PRD
2.6 — 3.95	S-621-A	934	
3.95 — 5.85	H-621-A	933	
5.85 — 8.2	C-621-A	932	
7.05 — 10.0	W-621-A	931	
8.2 — 12.4	X-621-A	930	465
12.4 — 18.0	Y-621-A	929	
18.0 — 26.5	K-621-A	928	
26.5 — 40.0	U-621-A	V-927	
33.0 — 50.0	Q-621-A	Q-927	
50.0 — 75.0	M-621-A	M-927	487
60.0 — 90.0	E-621-A	E-927	

TABLE 5
90° BENDS
COAXIAL
UG-27A/U
UG-27B/U
UG-27C/U
WAVEGUIDE—H-PLANE

Frequency Range, kmc	Manufacturer's Model Number		
	FXR	Narda	PRD
2.6 — 3.95	S-624-B	354-H	
3.95 — 5.85	H-624-B	353-H	
5.85 — 8.2	C-624-B	352-H	
7.05 — 10.0	W-624-B	351-H	
8.2 — 12.4	X-624-B	350-H	463
12.4 — 18.0	Y-624-B	349-H	
18.0 — 26.5	K-624-B	348-H	
26.5 — 40.0	U-624-B	V-347-H	
33.0 — 50.0	Q-624-B	Q-347-H	
50.0 — 75.0	M-624-B	M-347-H	486
60.0 — 90.0	E-624-B	E-347-H	

described in Application Note No. 1. In place of separate units in the form of a Bolometer Preamplifier, BA-1, and Audio Substitution Attenuator, CF-1, a Model BA-5 Attenuation Calibrator is used. In this unit the Audio Substitution Attenuator precedes the amplifier so the amplifier operates at substantially a constant level during any one measurement. This eliminates any non-linearity of the amplifier as a possible source for error in the measurement. The output of the BA-5 supplies one input of the Differential Null Detector. The output indicator on the BA-5 is used only to monitor the level of the output of the measurement channel to insure that everything is operating in the proper range.

TABLE 6
ATTENUATORS
ISOLATION–RANGE EXTENSION

COAXIAL

Frequency Range kmc	Manufacturer	Model Number
D.C.- 1.0	Weinschel	50
D.C.- 1.0	Weinschel	11
1.0-12.4	Weinschel	210
1.0-12.4	Weinschel	503

WAVEGUIDE

Frequency Range kmcs	Manufacturer's Model Number			
	FXR	H.P.	Narda	PRD
2.6 – 3.95	S-151-A	S-375-A	734	171
3.95 – 5.85	H-151-A	G-375-A	733	162
5.85 – 8.2	C-151-A	J-375-A	732	161
7.05 – 10.0	W-151-A	H-375-A	731	160
8.2 – 12.4	X-151A	X-375-A	730	159
12.4 – 18.0	Y-151-A	P-375-A	729	189
18.0 – 26.5	K-151-A	K-375-A	728	190
26.5 – 40.0	U-151-A	R-375-A	V-727	191
33.0 – 50.0	Q-151-A		Q-727	
50.0 – 75.0	M-151-A		M-727	179
60.0 – 90.0	E-151-A		E-727	

TABLE 7
SLOTTED LINES
COAXIAL

Frequency Range kmcs	Manufacturer	Model Number
.02 – .6	B.J. Electronics	65
.1 – 3.0	B.J. Electronics	62
.5 – 4.0	H.P.	805-A
.45 – 4.0	Narda	230-N, 230-C, 230-⅝, 230-⅞, 230-SC
1.0 – 4.0	FXR	N-101-A†
1.0 – 4.0	PRD	215-A†
1.5 – 12.4	Narda	231-N, 231-C, 231-TNC†
3.0 – 12.0	H.P.	806-B†
4.0 – 10.0	FXR	N-201-B†
4.0 – 10.0	PRD	205-A†

WAVEGUIDE

Frequency Range kmcs	Manufacturer's Model Number			
	FXR	Narda	H.P.	PRD
2.60 – 3.95	S-101-A†	224†	S-810-†	209-A†
3.95 – 5.85	H-101-A†	223†	G-810-B/†	201-A†
5.85 – 8.2	C-101-A†	222†	J-810-B/†	204-B
7.05 – 10.0	W-101-A†	221†	H-810-B/†	202-B†
8.2 – 12.4	X-101-A†	220†	X-810-B/†	203-D†
12.4 – 18.0	Y-102-A	219†	P-810B/†	210-A
18.0 – 26.5	K-102-A	218*	P-815-A†	211-A
26.5 – 40.0	U-102-A	V-217*	K-815-A†	212-A
33.0 – 50.0	Q-103-A	Q-217*	R-815-A†	
50.0 – 75.0	M-103-A	M-217*		216
60.0 – 90.0	E-103-A	E-217*		

/Used with Universal Probe Carriage.

* Requires Detector Mount.

† Requires tuning probe—see table 8.

TABLE 8
PROBES

Freq. Range, kmcs	Manufacturer	Model Number
1.0 – 12.4	FXR	B-200-A
1.0 – 12.4	PRD	250-A tunable
.9 – 18.0	Narda	229 tunable
8.0 – 18.0	H.P.	444-A untuned
12.4 – 40.0	H.P.	446-A untuned

TABLE 9
VSWR INDICATORS

H.P.	415-B
PRD	277
FXR	B-810-A
Narda	441

TABLE 10
COAXIAL TUNERS

Frequency Range, kmcs	Manufacturer	Model Number
.20 – 2.0	Weinschel	DS-109LL
.40 – 4.0	Weinschel	DS-109L
.75 – 10.0	Weinschel	DS-109

WAVEGUIDE TUNERS

Frequency Range, kmcs	Manufacturer's Model Number			
	H.P.	PRD	Narda	FXR
2.60 – 3.95	S-870-A	309-A	964	S-311-A S-312-A
3.95 – 5.85	G-870-A	300-A	963	H-311-A H-312-A
5.85 – 8.20	J-870-A	305-A	962	C-311-A C-312-A
7.05 – 10.0	H-870-A	302-B	961	W-311-A W-312-A
8.2 – 12.4	X-870-A X-880-A	303-A	960	X-311-A X-312-A
12.4 – 18.0	P-870-A P-880-A	314-A	959	Y-311-A Y-312-A
18.0 – 26.5	K-870-A K-880-A	313-A	958	K-312-B
26.5 – 40.0	R-870-A R-880-A	312-A	V-957	U-312-B
33.0 – 50.0			Q-957	Q-312-B
50.0 – 75.0		323	M-957	M-312-B
60.0 – 90.0			E-957	E-312-B

A bolometer bias current supply is included in the Model BA-5. The bias current is derived from the plate voltage supply through dropping resistors to the barretter. In order to avoid any ripple components in the d-c supply, four RC networks are employed for decoupling. The impedance of the d-c supply at 1000 cycles per second is high compared to the impedance of the audio substitution attenuator to prevent loading of the barretter by the power supply. The biasing circuit includes a crystal diode in parallel with the barretter to limit the peak discharge current when the barretter is connected, thus preventing burnout of the barretter due to transients arising during connection or disconnection of the a-c power to the instrument or connection or disconnection of the barretter to the instrument.

The attenuation measurement is made by substituting attenuation in the audio portion of the measurement channel for the r-f attenuation of the unit under test. Since the audio voltage developed across the barretter is proportional to r-f power, a 30 db change in r-f level produces a 60 db change in audio level. The BA-5 provides an a-f attenuation range of 104 db corresponding to 52 db in r-f. Since the BA-5 is designed specifically for this application, it is calibrated directly in changes in r-f power level.

The last instrument to be considered is the Differential Null Detector, Model ND-1. This unit com-

TABLE 11
COAXIAL BOLOMETER MOUNTS

Frequency Range kmc	Input Connector	Transmission Line	Use Barretter Type No.	Manufacturer's Model Number				
				FXR	H.P.	Narda	PRD	Notes
0.02 – 1.5	UG-23/U	⅜″	2 of 3		476-A	560		a
0.10 – 10.0	UG-21/U	⅜″	1,2	N-210A				b, c
0.10 – 10.0	UG-21/U	⅜″	1,2	N-210B				b
0.50 – 10.0	UG-23/U	⅜″	8			561	627-A	a
0.50 – 10.0	UG-23/U	⅜″	9			561		a
1.0 – 4.0	UG-23/U	⅜″	4		475-B			d
1.0 – 10.0	UG-21/U	⅜″	1,2				612-A	d
1.0 – 10.0	UG-21/U	⅜″	1,2				613	b, c
1.0 – 10.0	UG-21/U	⅜″	1,2				613-M	b

a—Broadband
b—Requires external tuning
c—Requires external DC return
d—Self-contained tuning

WAVEGUIDE BOLOMETER MOUNTS

Frequency Range, kmc	Input Connector	Transmission Line	Use Barretter Type No.	Manufacturer's Model Number			
				FXR	H.P.	Narda	PRD
2.6 – 3.95	UG-53/U	RG-48/U	4		S-485-A	514	
2.6 – 3.95	UG-53/U	RG-48/U	12			534†	
3.95 – 5.85	UG-149/U	RG-49/U	2, 4		G-485-B	513	
3.95 – 5.85	UG-149/U	RG-49/U	12			533†	
5.85 – 8.20	UG-344/U	RG-50/U	2, 4		J-485-B	512	
5.85 – 8.20	UR-344/U	RG-50/U	12			532†	
7.05 – 10.0	UG-51/U	RG-51/U	2, 4		H-485-B	511	
7.05 – 10.0	UG-51/U	RG-51/U	12			531†	
8.2 – 12.4	UG-39/U	RG-52/U	2, 4		X-485-B	510	
8.2 – 12.4	UG-39/U	RG-52/U	2	X-211-A			
8.2 – 12.4	UG-39/U	RG-52/U	12			530†	
12.4 – 18.0	UG-419/U	RG-91/U	2, 4, 5		P-485-C	509	
12.4 – 18.0	UG-419/U	RG-91/U	11			529†	
12.4 – 18.0	UG-419/U	RG-91/U	5	Y-205-B			
18.0 – 26.5	UG-425/U	RG-66/U	10				620
18.0 – 26.5	UG-595/U	RG-66/U	10				620-F-1
18.0 – 26.5	UG-425/U	RG-53/U	5	K-205-B			
18.0 – 26.5	UG-595/U	RG-53/U	5	K-205-F			
26.5 – 40.0	UG-599/U	RG-96/U	6	U-205-F			
26.5 – 40.0	UG-599/U	RG-96/U	7	U-206-F			
26.5 – 40.0	UG-599/U	RG-96/U	10				618-F-1
26.5 – 40.0	UG-381/U	RG-96/U	10				
33.0 – 50.0	UG-383/U	RG-97/U	7	Q-206-B			
50.0 – 75.0	UG-383/U	RG-98/U	7	M-206-B			
60.0 – 90.0	UG-387/U	RG-99/U	7	E-206-B			

† Fixed Tuned

pares the two 1000 cycle per second signals at the outputs of the two channels. As previously mentioned, before it is possible to obtain a null, it is necessary to adjust the two signals to the same amplitude and the relative phase of the two signals until they are exactly in phase. Both signals are derived from the same square wave modulated r-f source and would have a fixed phase relationship if it were not for the possibility of a difference in the phase shift in the audio portions of the two channels. To compensate for this, a variable phase shifter is provided in one channel of the ND-1. With the phase shifter and a phase reversing switch, the relative phase can be adjusted over the complete range of 360 degrees. The design of the phase shifter is such that variation of the phase over this range results in a negligible change in amplitude. Following the phase shifter, the two signals are fed to a differential transformer which produces an output proportional to the difference between the two signals.

The phase shifter, differential transformer and associated networks are designed for the fundamental of the 1000 cycle per second signal. Any harmonics of this signal which may be present in the measurement or reference channel will not, in general, be balanced out in the differential transformer and will pass the amplifier to give a reading on the unbalance indicator and thus reduce the sensitivity of the measurement. To prevent this, a filter is used to reject all harmonics of the 1000 cycle per second signal. It also prevents

broadening of the null due to any 60 cycle or 120 cycle hum that might be present on the signal.

Since it is desirable that the unbalance indicator operate for large as well as small unbalance signals without overloading, a lin-log amplifier is used. The small signal gain of this amplifier is enough to produce at least a 10% of full scale deflection for variations of attenuation of .003 db in the r-f portion of the measurement channel.

The use of this type of amplifier obviates the need for a gain control and at the same time allows an ac curate null indication. It also has the advantage o not going off scale with an accidental misadjustmer as a null is being approached.

The amplifier is followed by a rectifier circui with the unbalance indicator meter between tw cathode followers, one of which is driven by the rect fied signal. This arrangement balances out the effec of small plate and heater voltage fluctuations on th meter balance point.

TABLE 12 – 200 OHM BARRETTERS

* Type	Fits Mount For	Shielded	Unshielded	DC Bias MA	Manufacturer's Model Number FXR	Narda	PRD	Sperry	Special Features	For Coaxial	For Waveguide
1	1N21	x		4.5						x	
2	1N21		x	4.5	Z-220-C		610-A			x	x
2	1N21		x	4.5		N-610-B-4.5				x	x
2	1N21		x	8.75	Z-220-A					x	x
2	1N21		x	8.25	Z-220-B					x	x
2	1N21		x	8.75		N-610-B				x	x
3	1N21		x	8.75		N-610-B-100			Use 2	x	x
4	0.193" dia. 0.812" long		x	8.75		N-821-B		821		x	x
5	1N26	x		4.5			614		12.4-26.5 kmc		x
5	1N26	x		8.75	Z-221-A				12.4-40 kmc		x
6	Modified 1N26	x		8.75	Z-221-B				26.5-40 kmc		x
7	1N53	x		8.75	Z-222-A				26.5-90 kmc		x
8	Special Mica Strip		x	4.5		N-603-4.5	631-C		0.5-10 kmc	x	
9	" "		x	8.75		N-603			0.5-10 kmc	x	
10	" "		x	4.5			617		18-40 kmc	x	x
11	Miniature		x	8.75		N-604			8.2-18 kmc		x
12	1N21		x	8.75		N-605			(Low Inductance) 1.1-10 kmc		x

The barretters with lower bias current require about 2 db less r-f for the same 1000 cps output. They may burn out if 4 milliwatts r-f power are added while those with higher bias current may burn out if 16 milliwatts r-f power are added.

See COAXIAL BOLOMETER MOUNTS, Table 11.

Conclusion

A system has been described that is suitable for measurement of insertion loss up to 20 db with an accuracy of .02 db per 10 db at any frequencies for which power sources and bolometers are available. This range is limited by commercially available bolometer mounts to from 20 mcs. to 90,000 mcs. The application of Weinschel Engineering's Attenuation Calibrator, Model BA-5 and Differential Null Detector, Model ND-1 is described. These units were specifically designed for this type of measurement. To increase the range of insertion loss measurements, partial r-f substitution can be used providing sufficient power from the source is available. For example the range can be extended to 40 db if the source can deliver an output of 200 milliwatts.

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No. 154
Rev. Jan. 1959
Printed in U.S.A.

TEST RECORD

WEINSCHEL ENGINEERING
KENSINGTON, MARYLAND

ATTENUATION CALIBRATOR — MODEL BA-5

DATE 6-26-61 — SERIAL NUMBER 578

CUSTOMER _____ — JOB NUMBER _____

1. Attenuator Accuracy

Attenuation Setting	db Error Audio Power	db Error RF Power
32 db	.026 db	.013 db
22 db	.018 db	.009 db
12 db	.016 db	.008 db
2 db	.012 db	.006 db
1 db Step (Max. Dev.)	.016 db	.008 db
Variable (Max. Dev.)	.006 db	.003 db

2. Peak Frequency 6000.5 cps

3. Bandwidth (3db Points)
Low Frequency 989 cps — High Frequency 1011 cps

4. Input Voltage (Full Scale Meter Defl.) Output Voltage 1.52 V
(Min. Gain) 3.0 mV — (Max. Gain) .32 μV

5. Noise (referred to the Input) 27.5 MμV

6. Gain Stability (Output Meter Reading)
105 VAC 1.30 db — 130 VAC 1.28 db

7. Bolometer Bias Current (Max.) 9.5 M.A.

8. Output Meter Accuracy
(0-5 db) Max. Dev. (RF) .1 db
(5-10 db) Max. Dev. (RF) .2 db

Tested by _____ Engineer _____

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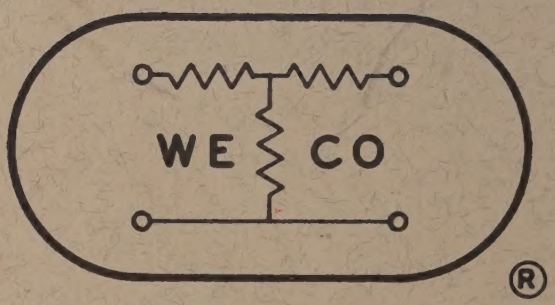

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